DOCUMENT RESUME

ED 097 195 SE 017 318

TITLE	Physics Handbook: Activities for a Modern Program in Physics.
INSTITUTION	New York State Education Dept., Albany. Bureau of Secondary Curriculum Development.
PUB DATE	70
NOTE	193p.
EDRS PRICE	MF-$0.75 HC-$9.00 PLUS POSTAGE
DESCRIPTORS	*Instructional Materials; Laboratory Experiments; *Physics; *Science Activities; Science Education; *Secondary School Science; *Teaching Guides; Units of Study (Subject Fields)

ABSTRACT

This handbook contains information that has been used in the high school laboratory by many teachers. Most of the experiments can be adapted for use as individual laboratory exercises or as teacher-student demonstrations. The resource material in this handbook should be helpful to all physics teachers as they continue to adapt their courses to satisfy the ever-expanding concepts and processes of physics. Four areas are included in this manual: (1) Kinematics, (2) Waves, (3) Electricity, and (4) Radiation Phenomena. An index to learning activities is included in the handbook and the appendix presents a list of suggested and necessary apparatus and supplies required to carry out the activities of the handbook. (EB)

ED 097195

PHYSICS HANDBOOK

U S DEPARTMENT OF HEALTH
EDUCATION & WELFARE
NATIONAL INSTITUTE OF
EDUCATION
THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL NATIONAL INSTITUTE OF EDUCATION POSITION OR POLICY

ACTIVITIES FOR A MODERN PROGRAM IN PHYSICS

SE 017 318

The University of the State of New York/The State Education Department
Bureau of Secondary Curriculum Development/Albany, New York 12224
1970

THE UNIVERSITY OF THE STATE OF NEW YORK

Regents of the University (with years when terms expire)

1984	Joseph W. McGovern, A.B., LL.B., L.H.D., LL.D., D.C.L., Chancellor	New York
1985	Everett J. Penny, B.C.S., D.C.S., Vice Chancellor	White Plains
1978	Alexander J. Allan, Jr., LL.D., Litt.D.	Troy
1973	Charles W. Millard, Jr., A.B., LL.D., L.H.D.	Buffalo
1972	Carl H. Pforzheimer, Jr., A.B., M.B.A., D.C.S., H.H.D.	Purchase
1975	Edward M. M. Warburg, B.S., L.H.D.	New York
1977	Joseph T. King, LL.B.	Queens
1974	Joseph C. Indelicato, M.D.	Brooklyn
1976	Mrs. Helen B. Power, A.B., Litt.D., L.H.D.	Rochester
1979	Francis W. McGinley, B.S., LL.B., LL.D.	Glens Falls
1980	Max J. Rubin, LL.B., L.H.D.	New York
1971	Kenneth B. Clark, A.B., M.S., Ph.D., Litt.D.	Hastings on Hudson
1982	Stephen K. Bailey, A.B., B.A., M.A., Ph.D., LL.D.	Syracuse
1983	Harold E. Newcomb, B.A.	Owego
1981	Theodore M. Black, A.B.	Sands Point

President of the University and Commissioner of Education
Ewald B. Nyquist

Executive Deputy Commissioner of Education
Gordon M. Ambach

Deputy Commissioner of Education
Herbert F. Johnson

Associate Commissioner for Instructional Services
Philip B. Langworthy

Assistant Commissioner for Instructional Services (General Education)
Bernard F. Haake

Director, Curriculum Development Center
William E. Young

Chief, Bureau of Secondary Curriculum Development
Gordon E. Van Hooft

Director, Division of General Education
Ted T. Grenda

Chief, Bureau of Science Education
Hugh B. Templeton

FOREWORD

Significant and far-reaching changes were made in the recent revision of the physics syllabus. These changes reflected both the recommendations of the Physics Syllabus Committee and the impact of current developments in physics and physics teaching. The new syllabus features changes both in content and in the approaches emphasized in this quantitative, laboratory-oriented science. The resource material in this handbook should be helpful to all physics teachers as they continue to adapt their courses to satisfy the ever-expanding concepts and processes of physics.

The information in this handbook has been used in the high school laboratory by many teachers. Most of the experiments can be adapted for use as individual laboratory exercises or as teacher-student demonstrations. The materials for the earlier edition of this handbook were compiled by Thomas Miner, then at Garden City High School, in his capacity as consultant to the Bureau of Secondary Curriculum Development. Several other physics teachers contributed favorite activities and made other suggestions during the development of that manuscript.

The preliminary drafts for the new edition of the handbook were prepared by Herbert Gottlieb, Martin Van Buren High School, New York City. Suggestions and revisions were made by Mr. Miner, now of Yeshiva University, New York City, and Robert MacGregor, of the New York State Education Department, Bureau of Secondary School Supervision. Sigmund Abeles, now of the Connecticut State Department of Education and John Fitzgibbons, Cazenovia Central High School, developed additional materials for this publication. Edward Lalor, Associate in Science Education, coordinated the project under the direction of Hugh B. Templeton, Chief, Bureau of Science Education. Robert F. Zimmerman, Associate in Secondary Curriculum, reviewed the manuscript and prepared it for publication.

Gordon E. Van Hooft
Chief, Bureau of Secondary Curriculum Development

William E. Young
Director, Curriculum Development Center

MESSAGE TO TEACHERS

The high school course in physics provides students with meaningful experiences which are concerned with the utilization of energy, application of forces, and concept development in the areas of electronics, magnetism, and radioactivity.

Mastery of the basic understandings of physics phenomena may provide students with concepts which are essential to their survival in a world of ever-increasing complexity. The physics phenomena are an integral part of the fabric of the technological society of which we are all a part. The pragmatic approach of "learning-by-doing" is inherent to the laboratory-investigations-approach physics course. The knowledge obtained by students from meaningful manipulation of laboratory materials can have a profound effect upon their lives by increasing their awareness of the environment of which they are a part.

The aims and objectives of a physics course should extend far beyond the acquisition of knowledge about the utilitarian applications of physical principles. Indeed, such practical illustrations probably serve the student best when they are used as vehicles for less tangible educational goals. The physics course should be the practice laboratory in which the attitudes of the so-called "scientific method" are not merely recognized and recited, but are reinforced by use. The course should have sufficient cohesion to afford a glimpse of the orderliness of the patterns in the complex mosaic of the universe. The part played by mathematics as an expression of this systematic organization should be brought home to the physics student.

The physics course should also combat an attitude of passive confidence that science has an answer for all questions, and the tendency to take for granted that which is familiar. Both of these dangerous blocks to progress have been fostered by the wealth of material contributions that science has made to daily life. We should try to neutralize this "degenerative feedback" by substituting a habit of inquiry into hidden interrelationships and an appreciation of the inherent inability of science to give a final and complete answer to any fundamental question.

Physics teachers should resist the temptation to attract students by dilution of the subject matter of physics. Instead, the emphasis of the course must be turned from fact collecting to comprehension, from an unsatisfying skimming of many topics to a more thorough and gratifying study of fewer subjects. Rather than attempt to make the course content easier, teachers should evaluate their work to discover where it is going stale and how it can be revitalized.

An aspect of physics enrollment which has received too little attention is the rejection of physics by girls. The benefits to be looked for in studying physics show no sex discrimination. School administrators and guidance officers should be aware of this fact.

A well-planned laboratory will make provisions for independent exploration on the part of the individual pupil. The acquisition of unusual apparatus and supplies for such projects is often more than paid for by the resulting student-constructed device, which may be used in future years for demonstration purposes. Students engaged in project work need a place where their equipment can be stored, preferably without disassembly. The physics teacher should be freed from other duties at regular times to allow him to supervise this important phase of learning.

It is more expensive to set up and equip a classroom-laboratory for physics than for any other science. This is caused by the great diversity of items needed, and the cost of some necessary individual pieces. However, no other science lends itself so well to the attainment of the proper goals of demonstration and activity work, so that the expenditure is amply justified.

The teacher's part in presenting a demonstration is to stimulate desirable mental activity on the part of his students. This means that he should have a very clear view of the points he wishes his demonstration to make, and know exactly how these points are going to be evidenced. He must present the activity in an attention-gripping manner, and must be ready to lead and respond to the discussion which is necessary to raise his demonstration above the level of mere entertainment.

Demonstrations are used to serve several purposes:

- To introduce a new topic, and to provoke profitable introductory discussions
- To illuminate a concept which has already been, or is being, taught
- To promote creative thinking by presenting an apparently unrelated or inconsistent phenomenon for explanation
- To give real dimensions to a verbal description or explanation

Equipment to be used before a class should be as large and simple as possible. All needed pieces should be at hand before the class assembles, and where the nature of the demonstration permits, it is good practice to put it together in view of the class. When a demonstration requires more than ordinary handling of apparatus, it may be assembled in permanent form, to be stored for use in following years. All procedures and parts should be checked for visibility from all stations in the room, both as regards size and lighting.

Chalkboard diagrams are useful in helping a class understand the construction, placement, and connection of equipment. Sketches should be drawn and labeled with some care. Planning diagrams in advance can avoid much confusion.

Time and facilities needed for teaching physics differ greatly from school to school. The required portions of the physics syllabus, the basic core, and any two of the four extended areas form a minimum nucleus which all physics students should cover. Teachers are urged to include optional materials in their course as time permits and student and teacher interests prompt. A field of study which cannot be covered by the class may well be used as additional material to enrich the course for students of superior ability.

High school physics students should be encouraged to use slide rules in making routine computations. For those who are going on to science-related careers the skill will find a lifetime of use, and, for the others, it is at the very least a timesaving device. The slide rule is ideally introduced in the elementary physics course, since physics supplies sufficient problem material for practice, and finds students mature enough in their mathematical comprehensions to appreciate the instrument without using it merely as a substitute for necessary arithmetical skills.

LABORATORY SAFETY

A laboratory instructor must be constantly alert for the safety of his students. The most important safety precaution is achieved in establishing a working atmosphere in the laboratory. The freedom of individual action that is necessary to a successful laboratory is sometimes interpreted by students as license, and while discipline in the laboratory cannot take the same form as in class, it should be just as well defined. A distraction from the actual laboratory problem being investigated can cause an accident, and such accidents are inexcusable.

CONTENTS

Page

Foreword iii

Message to Teachers iv

Area One: Kinematics 1

Area Two: Waves 51

Area Three: Electricity 101

Area Four: Radiation Phenomena 143

Index to Learning Activities 175

Appendix 184

AREA ONE

KINEMATICS

1.01. VECTOR AND SCALAR QUANTITIES

Examples from common experience can be used to help with the understanding of vector and scalar quantities.

Scalar quantities involve *only* a magnitude. Common examples are: the capacity of a container, the length of an assignment, the score of a game, the candlepower of a lamp, the speed with which a girl can knit a sweater, the length of a pendulum, and the area of a football field. Note that "speed" and "length," as distinguished from "velocity" and "displacement," are scalars in these illustrations because no direction is essential to their complete description.

Vector quantities have both magnitude and direction and cannot be completely identified without both. For example: a student's weight, the pull of a tractor on a cultivator, a trip made by car to the next village, the velocity of a rifle bullet, wind velocity, and the tension in a suspension bridge cable.

1.02. MEASURING DISTANCES AND DISPLACEMENTS

The value of measuring distances, which have the appropriate number of significant figures, can be presented with a simple demonstration using four specially marked meter sticks.

Cover the first meter stick with paint or paper so that all of the markings are hidden. Using this unmarked meter stick, have pupils measure the length of a laboratory table. After several trials, it will be found that the measurement to the nearest number of whole meters is certain but that there is some variation in the estimations to the nearest tenth of a meter. The results of these measurements are considered to be accurate to two significant figures: one certain and the second estimated.

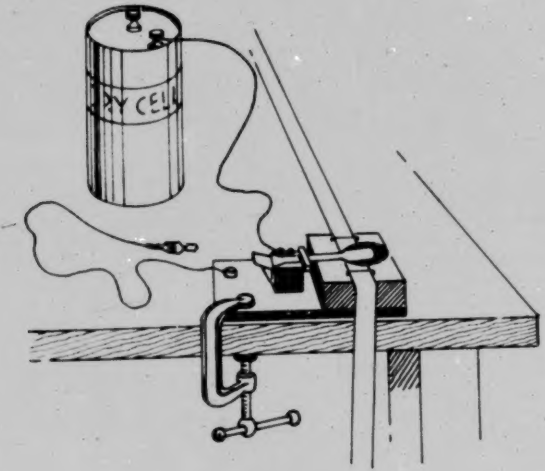
Repeat the measurements on the same lab table using a second meter stick which has markings spaced at 10-centimeter intervals. After several trials, pupils will be able to obtain results having three significant figures: two of them certain and a third estimated.

Using a third meter stick marked at 1-centimeter intervals will provide measurement to four significant figures. It will be found, however, that these measurements cannot be easily repeated unless special measuring techniques are discovered to avoid parallax, end error, and other experimental sources of error.

Finally, have the pupils attempt to obtain measurements to five significant figures using a conventional meter stick with markings spaced at 1-millimeter intervals. It will be extremely difficult, if not impossible, to obtain repeatable measurements with ordinary measuring techniques and a conventional meter stick. Therefore, pupils will not be justified in reporting such a measurement to five significant figures unless the measurements are reported together with a detailed description of the special measuring techniques which made the results possible.

1.03. CALIBRATING A TICKER TAPE TIMER

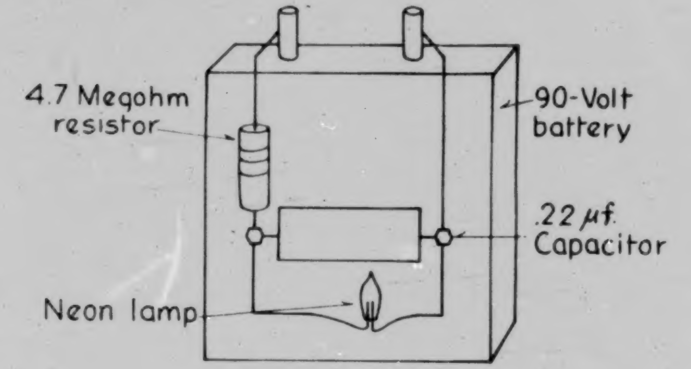
A ticker tape timer is useful in measuring the distances that are traversed by moving objects during intervals as short as a fraction of a second. These inexpensive timers may be purchased from a number of scientific supply companies or may be made by removing the gong from a doorbell and placing a strip of paper tape under the clapper. Insert a piece of carbon paper between the paper and the clapper so that a carbon dot is produced each time the clapper operates. These dots are made at fairly regular intervals when the timer is operated by a fresh dry cell or by a bell transformer. To determine the time between two successive dots (the period of the timer) pull the paper tape past the vibrating clapper for a known interval of time such as 5 seconds. Dividing this time interval by the total number of dots that appear on the tape establishes the period of the timer. After a few repeated trials, confidence in the timer is gained by observing that the results are fairly consistent.



1.03a. RELAXATION OSCILLATOR LIGHT SOURCE

A technique which may be used to produce stroboscopic photographs involves the use of a relaxation oscillator as a light source. To make the relaxation oscillator (a "blinky"), a capacitor, a resistor, and a neon lamp are connected to a small 90-volt battery as shown in the diagram. Using the values indicated, the lamp will blink approximately once a second. Since the entire apparatus is compact, it can be placed directly on a small cart, or some other object, whose motion is under investigation. The camera lens is opened in a darkened room and as the object under investigation is moved, its position is recorded on the film each time the lamp flashes. The blinking rate may be increased by substituting a resistor of lower value or may be decreased by using a larger resistance. For quantitative results a scale may be photographed on the same picture by a double exposure. After photographing the trail of "blinky" flashes, the camera shutter is closed, the room lights turned up, and with the camera position unchanged a snapshot is taken of a meter stick located along the path taken by the flashing lamp. The points of lights are thus superimposed on the image of the meter stick. With the flash frequency and the distance known, the velocity and acceleration can be readily computed.

A camera using cut film, or which has a back that opens, may be used in order to produce rapid prints of the procedure. A Polaroid camera has the advantage of producing a print instantly. By using a Polaroid camera, the entire laboratory exercise can be completed in a single period. Students should be encouraged to do this experiment on a small group basis. When results are compared, sources of error can be determined and minimized.



1.04. UNIFORM VELOCITY

Uniform velocity is difficult to demonstrate because most moving objects are either slowed down by friction or they are speeded up as various forces are applied to keep them in motion. In some of the battery operated toys, however, the force of the motor and the friction of the gears achieve an equilibrium condition after a short while and the motion is fairly uniform. Attach such a device to a length of ticker tape so that it is moved through a timer (see activity 1.03). A graph made by plotting the distance between each fifth dot versus the time represented by the five dots should furnish the straight line relationship that is characteristic of uniform velocity. If two or more toy cars, having different speeds, are available, it is worthwhile to plot the distance versus time parameters for each car on the same piece of graph paper and determine the relationship between the relative speeds of the vehicles and the slopes of the respective graphs that are produced.

Devices such as air pucks and air tracks, which are practically frictionless, are now available from commercial sources. Most of these devices operate on the principle that friction is reduced when a cushion of air is interposed between the moving object and the supporting surface. Demonstrations of uniform velocity with one of these devices provides convincing evidence that an object tends to maintain a uniform velocity in the absence of an applied external force.

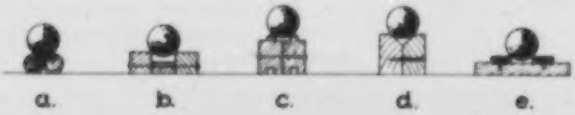
1.05. UNIFORM ACCELERATION

The concept of acceleration, as being the rate of increase of velocity resulting in greater distances traveled during successive time intervals, is difficult to show with free fall because of the magnitude of the acceleration. The acceleration of gravity may be "diluted," however, in several ways, and the consequently decreased motion and increased time make observation easier.

a. One of the simplest methods of studying acceleration is by use of a roller on an incline. If a ball is to be used, it may roll in a groove between: a) two steel rods, b) two strips of wood, c) tongues of two flooring boards, d) corners of two chamfered boards nailed together, or e) two parallel pieces of bandiron screwed to a board. Such an incline should be 6 to 8 feet long with one end elevated enough so that the ball rolls smoothly and slowly in the groove.

A brass cylinder such as 100-gm. standard mass, if started accurately, will roll smoothly down a flat plank. A strip of glass 2 or 3 feet long and 5 inches wide makes a low-friction incline down which a weight will roll very well.

In either case, the length and time can be measured and the final velocity and acceleration computed.



The ball also can be permitted to roll onto a section of track which has been previously adjusted to slope just enough so that the ball neither accelerates nor decelerates. If the time it spends on this section of the track and the track's length are measured, the final velocity can be computed. From this find the average velocity on the incline and, by using the length of the incline, calculate the time spent in accelerating and the acceleration. This could be compared with the acceleration measured previously.

b. The incline mentioned above may terminate in a horizontal section on which the ball will be retarded for a study of deceleration.

c. A large, low-friction pulley is arranged to support two masses which differ slightly. By adjusting the difference in mass, acceleration can be made very slow.

d. A large yo-yo with a thin shaft will accelerate linearly very slowly.

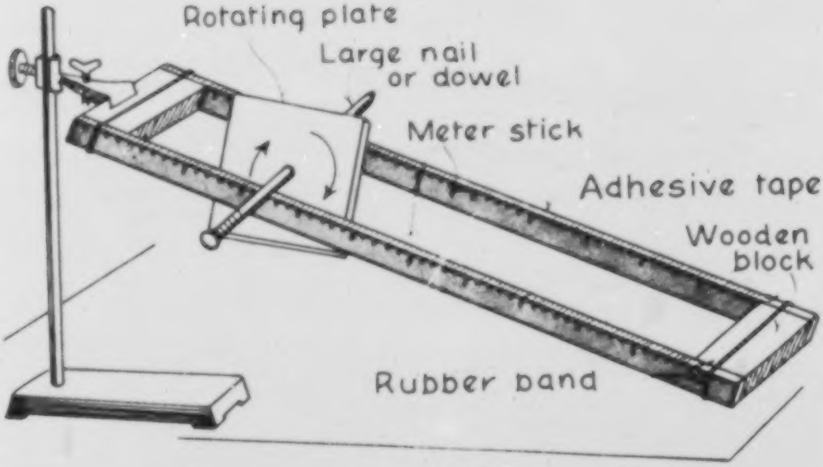
e. A low-friction car can be accelerated by the dropping of a weight at the end of a cord passing over a pulley.

f. With any of the above arrangements, a metronome or pendulum can be used to give equal time intervals, and the distance traveled in the successive intervals can be marked.

1.06. UNIFORM ACCELERATION WITH A ROTATING DISK

A rotating disk traveling downhill between two meter sticks will have a linear acceleration that can be accurately timed with the sweep-second hand of an ordinary watch.

The meter sticks with spacers and rubber bands are arranged as shown in the illustration on the next page. Cover the top edge of each stick with surgical or drafting tape to minimize slipping



during operation. A perfectly round disk might be desired to simplify any advanced calculations that pupils might wish to perform, but a square or any other shape will operate just as well as long as it is properly balanced. Use any flat piece of lumber approximately 6 inches square. Locate the center of gravity of the flat surface and drive a nail or dowel through this point so that it protrudes approximately 2 inches on each side. If the disk is not perfectly balanced, a slight amount of filing at the heavy edge is advisable.

To operate the apparatus, the disk is released near the top of the slope, and the time is recorded as its center covers distances in multiples of 10 or 20 centimeters. An alternate procedure is to record the distance that the center has traveled each 3 to 5 seconds following release.

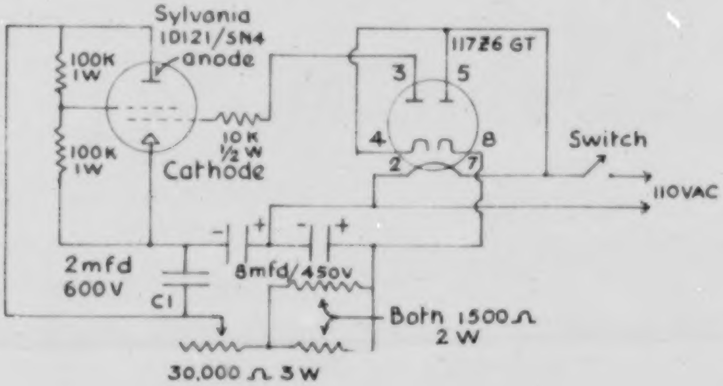
After several trials with the same slope, the pupils should have sufficient data to establish that the distance varies with the square of the time. The experiment might be repeated using different angles of slope. Graphical analysis of the data will reveal a family of curves which are interesting to analyze.

Because of the energy used to overcome rotary inertia, it is *not* possible to calculate g from the simple relationship $a = g \sin \theta$.

1.07. ANALYZING MOTION BY STROBOSCOPIC PHOTOGRAPHY

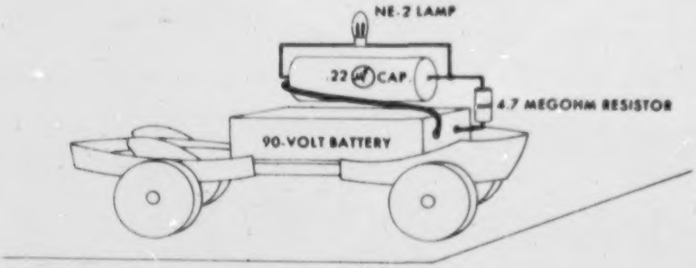
Multiple "strobe" exposures of a moving object can be ready for analysis in a few seconds by using a Polaroid camera. For best results, it is recommended that a dark background be prepared with neatly ruled distance markings. The apparatus should be positioned so that the object moves parallel to the plane of the film in the camera. If desired, special film may be obtained from the camera manufacturer to make transparencies suitable for instant projection.

a. If a commercial strobe lamp assembly is not available, one may be built using a Sylvania 1D121/SN4 strobe lamp and the electronic circuit shown in the diagram.

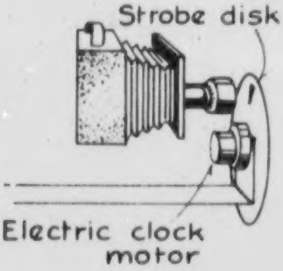


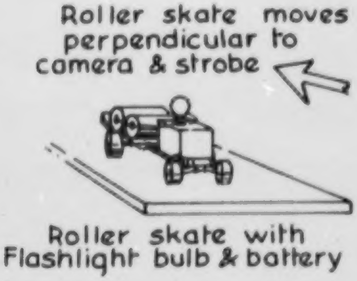
The lamp fits into a standard octal socket and the circuit uses standard parts. A photoflood reflector should be bolted to the socket to direct the light, and the circuit assembly should be enclosed for safety. The time between flashes is determined by the capacitance of C1. This can be varied within a small range by adjusting the 30,000 ohm potentiometer. For additional operating ranges, different values may be substituted for capacitor C1. If difficulty is experienced during operation, check the two 8-microfarad filter capacitors. To further stabilize the unit a voltage-regulating tube between capacitor C1 and the negative terminal of the nearest filter capacitor may be added.

b. A less expensive technique is to use a "blinky" relaxation oscillator as a light source. A capacitor, a resistor, and a neon lamp are connected to a 90-volt battery as shown in the diagram on page 3. Using the values indicated, the lamp will blink approximately once a second. Since the entire apparatus is compact, it can be placed directly on a small cart or other object whose motion is under investigation. The camera lens is opened in a darkened room and as the object is moved, its position each second is recorded on the film. The blinking rate may be increased by substituting a resistor of lower value or may be decreased by using greater resistances. Commercial apparatus is available.


NE-2 LAMP
.22 µf CAP.
4.7 MEGOHM RESISTOR
90-VOLT BATTERY

c. Another alternative is to mount a flashlight lamp and battery on the moving object so that the light is on continuously. The light is chopped into pulses by a strobe disk which is rotated in front of the camera lens by a synchronous electric motor such as a clock motor (about 300 rpm).


Strobe disk
Electric clock motor


Roller skate moves perpendicular to camera & strobe
Roller skate with Flashlight bulb & battery

This technique works best when:

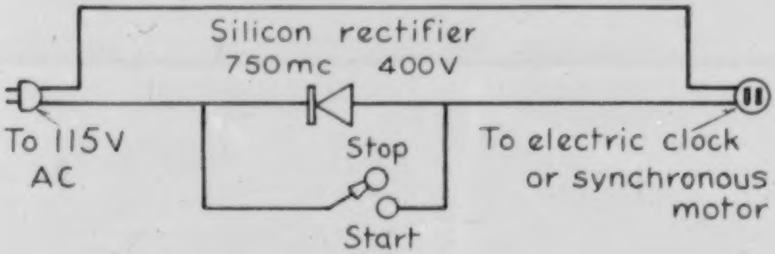
- exposure rates from 5 to 30 seconds are suitable.
- the disk is as close to the camera as possible.
- the lens is fully opened and taped to provide a slot similar to the slot on the disk.

- the shutter is not opened longer than is necessary to take the picture.
- a cable release and tripod are used.
- the background is dark (a dull black is best).

Some experimentation with slit width, lighting, and film speed will improve the quality of the pictures.

1.08. ELECTRIC STOP CLOCK

To use an ordinary electric clock as a precise stop clock, connect the simple adaptor, shown in the diagram, between the line cord and the electric source. A silicon rectifier applies direct current to the clock motor when the clock is stopped to prevent the hands from coasting. If automatic timing of a moving object is desired, it is suggested that a low-voltage relay be substituted for the switch. The safe voltage which controls the relay coil can then be operated by exposed mechanical microswitches or magnetic switches set at intervals along the path of the moving object. For measuring short intervals of time, a 300 rpm synchronous motor may be used instead of a complete clock. A strong, but lightweight pointer should be attached to the motor shaft and a dial should be calibrated so that a complete revolution is indicated to be 0.2 second.



1.09. MEASURING DECELERATION OF A FRICTION TOY

A meter stick, a stopwatch, and a toy automobile with a "friction" motor will provide quantitative data for determinations of uniform deceleration. The motor is operated gently and the car is released at a starting line on a lab table or on the floor. The time from release until the toy comes to a complete stop is recorded and the distance is carefully measured. Several trials must be made. The deceleration rate of the toy may be calculated using the relationship $a = \frac{2s}{t^2}$ after several trials. A distance versus time graph may be plotted and analyzed.

1.10. DEPENDENCE OF PENDULUM PERIOD ON "g"

The fact that the period of a pendulum depends on the acceleration of gravity rather than on its mass can be shown by placing a strong magnet under an iron bob suspended as a pendulum. This simulates an increase in *g* and results in a decrease in the period. The increased tension in the cord supporting the bob is just as if its weight had increased, without, however, increasing its mass. Use a bob of lead or wood to show that a change in mass has no effect on the period of the pendulum.

1.11. ACCELERATION OF GRAVITY WITH A PENDULUM

The simplest method of measuring *g* is by use of a simple pendulum. The formula to be used is $T = 2\pi \sqrt{L/g}$ where T is the period in seconds, and *L* the length in centimeters measured from the point of support to the center of the bob. In addition to yielding an approximate value for *g*, this experiment introduces the concepts of period and frequency. Starting a count with "0" rather than "1" is usually a new idea to the pupils. Accuracy can be improved by keeping the arc through which the pendulum swings small. Fifty or a hundred swings of the pendulum may be timed to get the period.

1.12. ACCELERATION OF GRAVITY INDEPENDENT OF MASS

Suspend two balls of the same size as high as possible above the floor by means of electromagnets. One ball is iron; the other is wood with a nail in it. (Two steel balls of different sizes may also be used.) Simultaneous release is assured by covering the pole of each magnet with a piece of tape to minimize the effect of residual magnetism. The magnets are connected, through a switch, to a dry cell. When the switch is opened, the balls will drop from the same height onto a metal pan or into a metal wastebasket, making a single sound as they strike.

1.13. EFFECT OF AIR RESISTANCE ON FALLING OBJECTS

a. The dependence of air resistance on area and the concept of terminal velocity can be shown with a sheet of paper. Dropped in a horizontal position, it quickly reaches its terminal velocity. Dropped edgewise, it plummets to the floor. Crumpled loosely, it falls quickly, but does not keep pace with a metal ball or coin dropped at the same time. Wadded into a tight ball and dropped with a metal object, it falls along with the other, and strikes the floor at about the same time.

b. The "guinea-and-feather" tube is used to show that the acceleration of freely falling objects is independent of mass if air resistance is eliminated. This is a large glass tube containing a feather and a coin. At normal pressure the feather flutters and the coin plunges as expected when the tube is inverted. But when air is removed, the feather and the coin drop together.

1.14. THE CONCEPT OF FORCES

The concept of a force as a push or a pull may be reinforced by calling attention to various familiar forces: weight, muscular contraction, molecular forces resulting in material strength and elasticity, and friction.

Identify weight as a force and justify the use of weight units in expressing the magnitude of forces. Hang a weight from a coiled spring and show that extensions of the spring caused by other forces can be expressed in weight units since they produce the same effect as weights.

1.15. COMPOSITION OF FORCES

a. Tie each end of a 2 meter length of cord to the hooks of two spring balances. Select a load so that its mass is about one-third the full-scale reading of one of the balances, and suspend the load from the center of the cord.

When the balances are held close together, the sum of their readings equals the weight or mass. As they are moved apart, their readings increase until, at an angle of more than 120 degrees, each reading is greater than the mass. Draw chalkboard diagrams to show how this is possible.

This experiment may also be a tabletop setup, with balances attached to clamps on vertical supports which can be moved apart.

b. The addition of vectors by the parallelogram method can be shown in a variety of ways.

(1) For purposes of demonstration it is probably best to have the force assembly placed against the chalkboard, so that the lines of action can be traced directly. Spring balances are supported about 5 feet apart from the rail above the chalkboard. Their hooks are connected by string. Another string is tied to the first, somewhat off

center, and the weights hang from it. The directions of the forces may be marked behind the strings on the board, and the balance readings recorded. Construct a parallelogram to scale on any two of the forces. Its diagonal is their resultant. It should be equal to the third force (their equilibrant) and opposite to it in direction. A major source of error is encountered if the weight of the balances causes the string to sag appreciably. In that case, support the balance in line with the string before marking the direction of its force or recording its reading.

(2) For individual use, the arrangement described above is hung from a horizontal support, force directions being marked on a paper held behind the cords. After showing that the resultant of the forces exerted by the balances is equal and opposite to the weight, rearrange the forces and angles for a second trial. This time, show that the resultant of the weight and one of the balance forces is equal and opposite to the force indicated by the other balance.

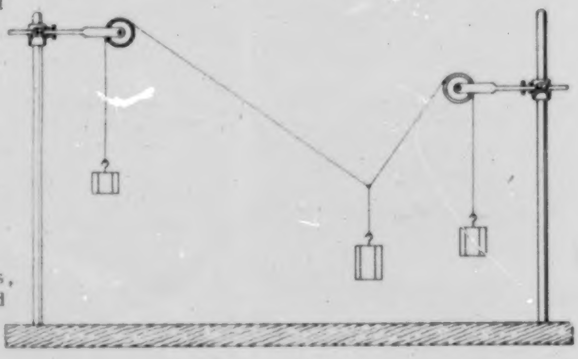
(3) Either of the above may use pulleys and weights instead of balances.

(4) Three balances may be held by a rectangular wooden frame placed in front of the chalkboard, or over a piece of paper.

(5) Table-edge clamps may be used to hold the balances, the arrangement of balances and cord resting flat on the tabletop.

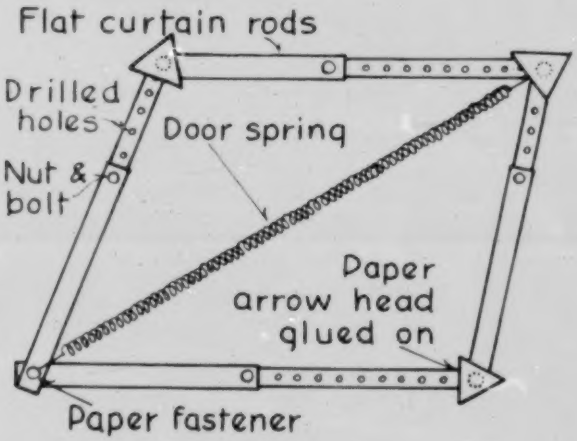
1.16. EQUILIBRIUM OF THREE CONCURRENT FORCES

During the work on composition of forces, have a demonstration at hand which can be manipulated to duplicate most possible three-force situations. Two pulleys are mounted on vertical supports, a string passed over the pulleys and a mass hung on each end of the string. A second string is tied somewhere near the middle of the first, and a third mass supported by it. By changing the size of the masses, the heights of the pulleys and the distance between the supports, a variety of combinations is possible. For successful results, the pulleys should be as friction-free as possible.



1.17. VECTOR ADDITION USING A CURTAIN ROD ANALOG

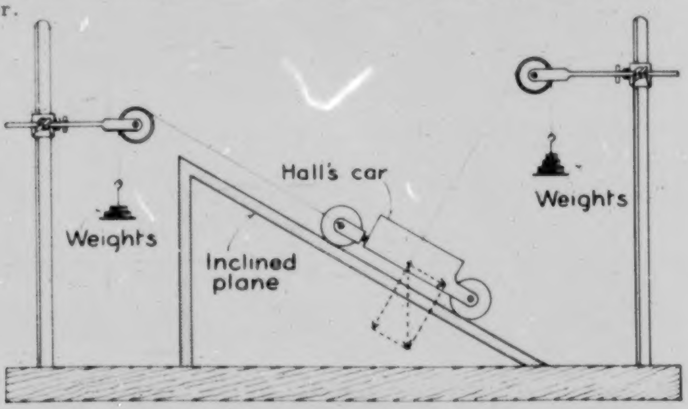
The addition of two vectors by the parallelogram method may be demonstrated with the aid of an apparatus consisting of a long coiled spring and four straight sections cut from a curtain rod. Drill holes in the curtain rods as shown in the diagram and fasten them together using eight paper fasteners. If a more permanent arrangement is desired, nuts and bolts may be used in place of the paper fasteners providing they are loose enough to permit the parts to move easily. The angle between the component vectors may be increased and the effect on the resultant may be determined by observing the length of a spring (or a chain of rubber bands) which serves as the diagonal of the parallelogram. To illustrate the effects of changing the magnitudes of the components, telescope the curtain rod sections as desired and observe the length of the resultant and the direction in which it points.



1.18. FORCES ACTING ON CAR ON INCLINE

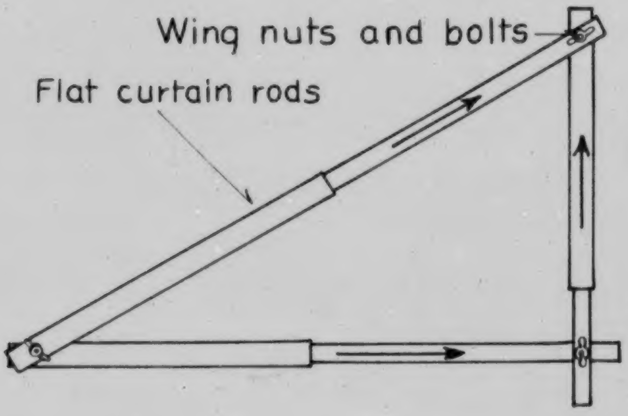
Adjust an inclined plane so that the angle of elevation will make the situation easy to analyze mathematically, (30 or 45 degrees) or so that its height and length have the ratio 3/5. Place a car on it and hold it in position by blocking the wheels. Have the class resolve its weight into forces parallel to and at right angles to the plane. Supply the equilibrants of these forces by strings passing over pulleys to weights. The plane may then be removed without disturbing the car.

This experiment is successful in a very dramatic way if care is taken to see that the strings are respectively parallel and at right angles to the plane, and if they are correctly centered on the car.


Hall's car
Weights
Weights
Inclined plane

1.19. VECTOR RESOLUTION INTO RIGHT ANGLE COMPONENTS USING A CURTAIN ROD ANALOG

In theory, any vector may be resolved into two or more components having an infinite variety of relative magnitudes and angles of action. Show how a vector may be resolved into two components at right angles to each other with a device consisting of three telescoping curtain rod sections bolted at their ends to form a triangle.


Wing nuts and bolts
Flat curtain rods

select one of the sections to represent the original vector and adjust the others to form a right triangle with the original vector as the hypotenuse. If the length of the original vector is determined and one of the acute angles is measured, the pupils can predict that the length of the side opposite the acute angle is equal to the diagonal multiplied by the sine of the acute angle. The length of the other component can be predicted by multiplying the diagonal by the cosine of this acute angle.

1.20. RESOLVING A FORCE INTO COMPONENTS

a. The resolution of a single small force into a pair of much larger forces can easily be shown. Tie a cord to an upright, and pass it over a pulley which is at the same height above the tabletop as the point of attachment of the cord. Hang a weight on the end of the cord. Then show that this large weight is lifted by the addition of a much smaller weight to the center of the horizontal section of the cord. Show by chalkboard diagram how the small force can be resolved into a large tension in the string.

b. Clamp a dial scale, such as is used in the kitchen or nursery, to an inclined plane. The type of scale with a movable face, to permit resetting the zero easily, is particularly convenient. Use for the load a low-friction roller or a car. If the roller or car is not available, a cylindrical hooked weight can be used with a loop of string tied from the hook on one end to that on the other. Hold it in position on the platform of the scale, by a cord passing over a pulley attached to a fixed upright or to the top end of the plane and having a balancing mass at its end. The cord must be parallel to the plane. Set the zero of the balance to suit the angle of the incline, set the roller in position and show that the force perpendicular to the incline is a component of the roller's mass, as is also the necessary mass at the end of the çord. Change the angle of the incline, reset the zero and show the change in the components. Draw vector diagrams on the chalkboard.

This can be treated quantitatively by selecting familiar angles for the incline. However, a balance of the type suggested is not accurate when used on other than a horizontal surface.

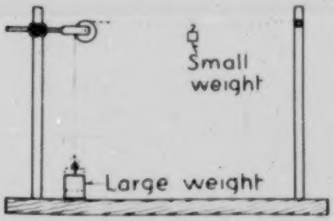
c. Show that a single force can be resolved into components along other directions. A compression balance for use as the boom *B* is sold commercially. Adjust the equipment so that the angle between the boom and the cord supporting the weight is a right angle. Measure the dimensions of the triangle formed by the boom, the upright, and the support which includes balance *S*. Have the students construct scale diagrams, first using these dimensions to determine the angles, then using a force scale to determine readings *S* and *B*, which may then be compared with the actual readings. Since the mass of the boom contributes to both these readings, a correction must be added to *W* before drawing the diagram. This correction can be obtained by removing *m*, unhooking *S* from the upright so that it can be held in a vertical position, and taking its reading while it is supporting the end of the boom.

If a compression boom is not available, the experiment can be performed by using a light stick or dowel for the boom. Butt it against the upright in any convenient way, and make the measurements suggested above. Then, in order to find the thrust in the boom, hook a spring balance into the screw eye at the end of the boom as shown at *P* and pull horizontally until the boom just leaves the upright. This balance reading is the thrust in the boom.

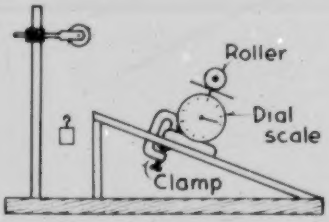
Any one of a number of other versions of this experiment may be employed as shown in the diagrams.

d. Have the students compute the tensions in two cords supporting a hanging mass. One of the cords is horizontal, the other at some angle (*A*) with the horizontal which makes calculation easy—say 30, 45 or 60 degrees. The cords pass over pulleys and are initially tied to clamps attached to the vertical supports holding the pulleys. Test the accuracy of the results by assembling masses to match the predicted tensions, disconnecting the cords from the clamps and substituting the masses.

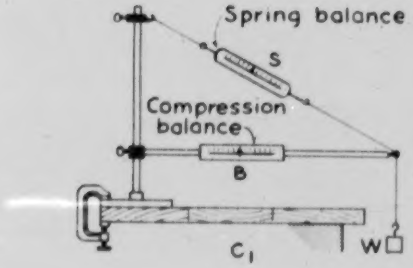
Show that the vertical component of the tension in the left cord (in the diagram) equals the mass, and that its horizontal component is the same as the tension in the horizontal cord.



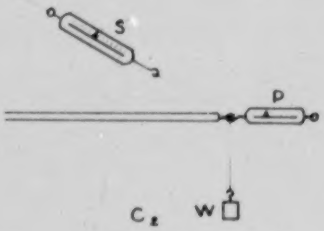
a



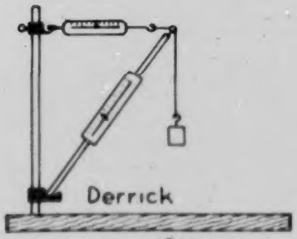
b.



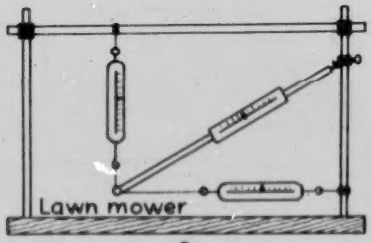
C_1



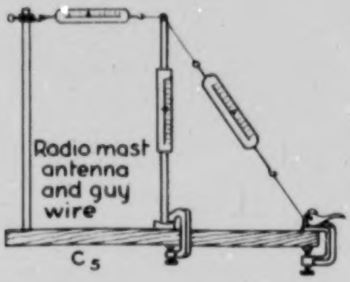
C_2



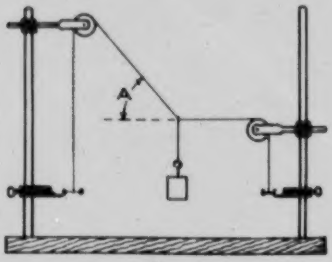
C_3



C_4



C_5



d

1.21. DEMONSTRATIONS OF INERTIA

There are many relatively simple demonstrations that will illustrate the principle of inertia for the pupil. The following are illustrative:

a. Snatch a piece of paper from underneath a glass of water after having shown that the glass can be dragged along by gently pulling the paper.

b. Stand a book on edge on a strip of paper and show that, if pulled slowly the book will move along with the paper, if pulled more quickly the book will fall over, and if the paper is snapped out, the book remains standing. Show how the laws of motion account for the behavior of the book in each of the three cases. Discuss the part played by inertia when subway strap hangers lurch as the train starts or stops suddenly. Call attention to inertia as the cause of injury and damage in automobile accidents.

c. Rest a coin on a card placed flat on the tip of one finger. Flick the card out from under the coin with a finger of the other hand. The card should be about the size of a calling card, and the coin a quarter or larger in order to make the demonstration effective.

d. Make a stack of 5 or 6 checkers and knock the bottom one out by striking it with a ruler. Repeat until you are down to the last checker. Coins can be used, and a hacksaw blade or knife blade used flat to strike out the bottom one.

e. Suspend a massive ball such as a 12-pound shot by a cord. The shot should be drilled at ends of a diameter for hooks. A similar cord is attached to the bottom. A gentle pull on the lower cord breaks the one supporting the weight. The falling ball may be caught in the hand or allowed to drop into a bucket of sand or onto a pad of rags. A sudden pull achieved by swinging the arm breaks the lower cord. Have pieces of string of the proper length and with loops tied in the ends ready for quick replacement.

f. Hang a heavy ball, with a hook on one side, as a pendulum. Using a length of light cord, show that the pendulum can be drawn aside if pulled gently, but that the cord breaks if yanked suddenly, resulting in almost no displacement of the pendulum. Attach the side string to a fixed upright, using a length that will be slack until the pendulum reaches the bottom of its arc. Draw the pendulum toward the upright and release. Note that the cord will break when it is pulled taut.

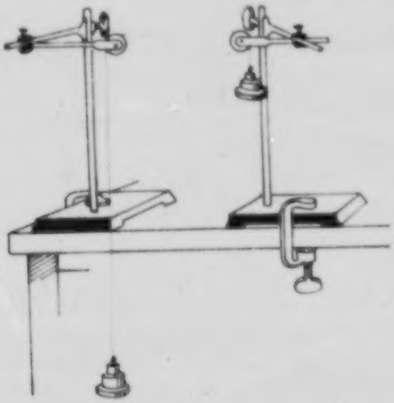
g. Use a large knife to cut part way through an apple or a potato. Then strike the knife, cutting-blade up, on the edge of the table to slice through completely. Or with the knife part way through the object, hold it in the air and strike the back of the knife a sharp blow to finish the cut.

1.22. NEWTON'S SECOND LAW

To illustrate Newton's second law support two pulleys as high above the floor as possible, pass a piece of cord over them long enough so that a weight hanger at one end touches the floor when a hanger at the other end is near the pulley. Put 150 gm. (made up of 100 gm., 20 gm., 10 gm., 10 gm., 5 gm., and 5 gm. standard masses) on one side and adjust the mass of the other to just enough more than 150 gm. so that it descends with uniform speed once started. (If boxes are used to hold the weights rather than weight hangers, it will avoid the necessity of picking up dropped weights during the experiment.)

Now if a 5-gm. mass is transferred from the first side to the second, there is a 10-gm. unbalanced force due to the weight of a 10-gm. mass, acting on a total mass of somewhat more than 300 gm. and the system will accelerate. Use a stopwatch to get the time it takes the mass to drop from its highest position to the floor, measure the distance and calculate the acceleration. Transfer another 5-gm. mass to double the unbalanced force and again compute the acceleration. Continue increasing the force and calculating the acceleration until the speed is so great that timing is unreliable. Show that the acceleration is proportional to the force by plotting the data on graph paper.

In similar fashion, by keeping the unbalanced force constant, the total mass can be varied and the acceleration shown to be inversely proportional to the mass. Variation in friction makes this inaccurate, but correcting for friction at each trial is tedious.

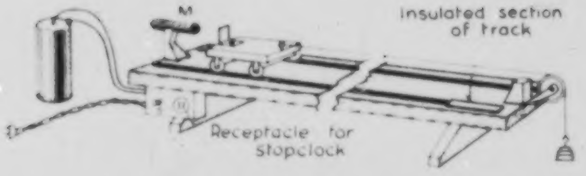


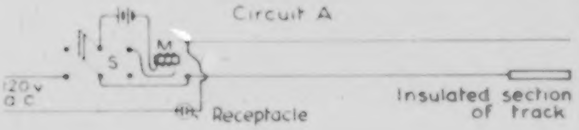
1.23. FORCE AND MOTION

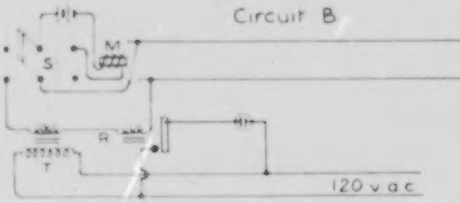
a. Spark timer method. One of the most difficult experimental procedures involved in measuring an acceleration is the timing operation. The uncertainty in the use of a hand-operated stopwatch is usually a significant fraction of the time being measured.

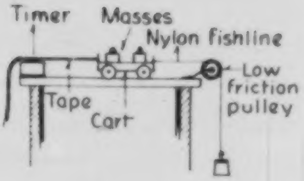
The apparatus in this experiment avoids this particular difficulty by using an electric stopclock (borrowed, perhaps, from the physical education or guidance departments), and having the experimental apparatus itself turn the clock on and off. Construct a track and car as shown in the diagram. The track uses metal rails at least 100 cm. long. These rails are insulated from each other, and form part of the stopclock circuit. The car has metal wheels and metal axles; these complete the circuit.

The car has a boxbody (not shown) in which masses can be placed and is accelerated by a weight hung from a cord passed over a pulley at the end of the track. It is held at the start by magnet *M* acting on a small iron plate. When switch *S*, a double pole, double throw snap switch is thrown, the magnet is turned off and the stopclock turned on. The clock runs until the car reaches an insulated section of the track, when its circuit is broken and it is turned off. The arrangement described is shown in circuit *A*. It has the disadvantage of exposing the 120 volts of the power line on the tracks.


M
Insulated section of track
Receptacle for stopclock


Circuit A
S
M
120 v a c
Receptacle
Insulated section of track


Circuit B
S
M
R
T
120 v a c


Timer
Masses
Nylon fishline
Low friction pulley
Tape
Cart

A circuit which avoids this difficulty is shown in *B*. This requires a step-down transformer and appropriate relay. A third possibility is not having the tracks complete the circuit, but having the car strike a switch at the end of the track to open the circuit.

In using this apparatus, measure the acceleration of a constant mass for a series of forces. An instructive way to analyze the results is to plot a graph of acceleration against force. This should result in a good straight line. The intercept on the force axis (the force which does not produce acceleration) is a measure of the friction of the system.

b. Tape timer method. The ticker tape timer may be used to make a quantitative determination of the relationship between force and acceleration.

Set up the apparatus as shown in the diagram. Place a set of metric masses on the cart (5, 10, 20, 50, and 200 gm.). Add mass to the end of the line until the cart moves across the table with uniform speed. Now attach the end of the tape to it. Remove a

5-gm. mass from the cart and hang it on the line. When the cart is released, the weight of the 5-gm. mass (about .05 nt.) will accelerate the system. The mass accelerated includes the mass of the cart, the masses on the line, and the line.

Repeat the experiment using 1-gm., 20-gm., 50-gm., and 100-gm. masses to accelerate the system.

Calculate the acceleration of the cart using the relationship $a = \frac{2s}{t^2}$ (where t is the time in "ticks" or dots.)

Plot the acceleration as a function of the accelerating force. A mass of 1-gm. weighs approximately (within 2 percent) 1×10^{-2} nt.

An interesting variation of this experiment is to hang the line over the edge of the table without a pulley. This, of course, increases the friction. If no masses are added to balance friction, the graph of acceleration as a function of force will not pass through the origin. Discussion of this can be most valuable.

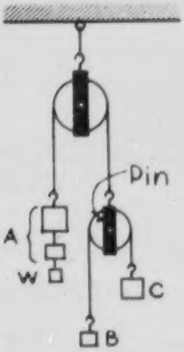
1.24. ACCELERATION AND FORCE

a. By hanging a mass from a spring balance, show that when the acceleration is upward the reading is greater than the mass. When accelerating downward, a smaller reading is obtained. When the velocity is uniform upward or downward, the reading is the same as the mass. Apply this principle to the tension in the cable supporting an elevator.

b. Prepare two identical small boxes, loading one heavily, leaving the other empty. Each should be of a size and shape that can be easily grasped in the hand. Ask a pupil to pick them both up quickly, one in each hand, and their difference in mass will be apparent to the rest of the class. The boxes must be closed, so that their difference in mass is not visible, and the operation must be performed with no hesitation.

1.25. SECOND LAW OF MOTION PUZZLE

As a challenging puzzle for pupils who have studied the second law of motion and discussed various of its familiar applications, set up the pulley problem illustrated. *A* is 3.0 nt., *B* is 1.0 nt., and *C* is 2.0 nt. A pin is caught in a hole in the hanging pulley, so that *C* cannot drop. *W* is added to *A* to balance the weight on the pulley, so that the system is in equilibrium. For the hanging pulley, choose one with a groove rough enough to prevent the cord from slipping, or pass the string twice around the pulley. Ask the class to predict the behavior of *A* when the pin is removed, by applying the second law of motion.



When the pulley is released, the tension of the cord supporting *B* and *C* becomes the same on both sides. For the total system to remain in equilibrium this would have to be 1.5 nt. keeping the downward pull on the pulley 3.0 nt. However, this would mean that the application of the same unbalanced force, (1.5 nt.) to each of two different masses, would result in the same accelerations - an impossible situation.

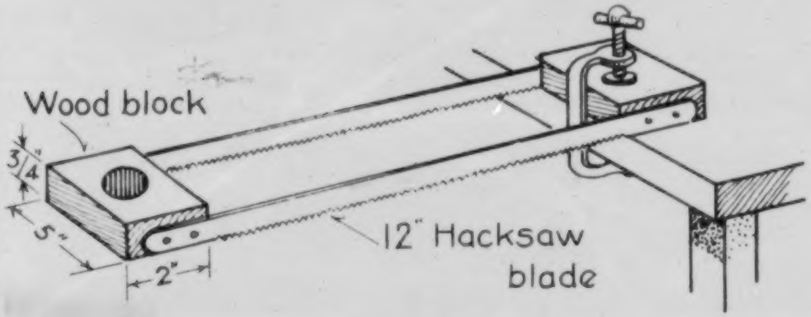
If the tension in the cord supporting *B* and *C* is less than 1.5 nt. *A* will accelerate downward, if the tension is more than 1.5, then *A* must accelerate upward.

Consider that portion of the system which consists of *B* and *C*. *B* and *C* are attached to the same piece of string and must accelerate at the same rate. The masses of *B* and *C* are approximately 100 gm. and 200 gm. respectively. Therefore the net force on *C* must be twice the net force on *B*. The net force on each mass is the difference between its weight and the tension in the string. Hence, the tension must be closer to the weight of *B* (1.0 nt.) than it is to the weight of *C* (2.0 nt.), or less than 1.5; and *A* accelerates downward.

1.26. INERTIAL AND GRAVITATIONAL MASS

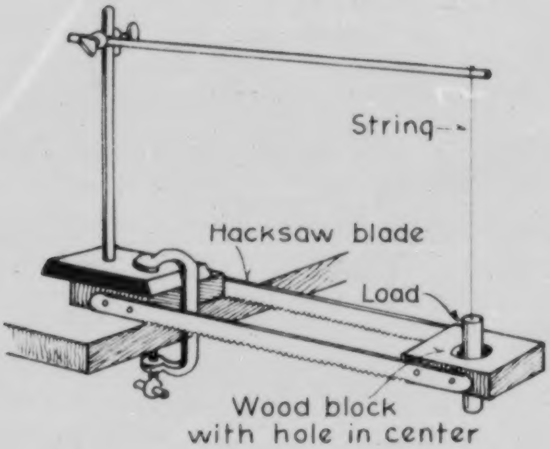
The concept of gravitational mass is sometimes difficult to grasp because of its close association with weight. It is often advantageous to start with a determination of the inertial mass of the object using a simple inertial balance.

An inertial balance may be assembled by fastening together two hacksaw blades and two wooden blocks as shown in the diagram on the next page. In operation, one end of the balance is clamped to a table and the other end is allowed to extend over the edge so that it is free to vibrate in a horizontal plane. If the free end is moved approximately 2 gm. to the side of its rest position and then released, the period of its vibration will be found to depend upon the inertial mass of the moving block. This mass can be varied by attaching several identical clamps or other convenient loads to the block, one at a time, and timing the period that is associated with each mass. Examination of a graph made by plotting the number of unit loads versus the vibration period should lead to the conclusion that the two factors are related. This may be followed by placing the unit loads on a scale in the same sequence and plotting the number of unit loads versus the weights indicated. When this data is graphed and examined, certain similarities will be evident between the two graphs.



1.27. MASS OF A "WEIGHTLESS" OBJECT

A convincing demonstration which shows the effects of inertial mass on a "weightless" object can be simulated by supporting the entire mass of a load by a long string so that the load hangs in the center of an inertial balance platform but does not touch it in the rest position. The periods of any horizontal vibrations will be found to be related to the mass of the load. Since the downward pull of the mass is balanced by the upward force of the string, the object may be considered to be weightless for practical purposes. Additional "weightless" masses may be added to the load to show that the inertial balance can differentiate among these string-supported loads by changing its vibration period.



1.28. METRIC MASS AND WEIGHT MEASURES

Weigh objects in both systems to show the relationship between the pound and the newton. Express familiar weights in dynes and newtons. Kitchen cabinets will have cans and boxes whose masses are expressed in grams as well as the weight in ounces. Display examples.

Point out the fact that one of the major merits of the metric system lies in the relationship between its unit of length and mass; one cubic centimeter of water having a mass of almost exactly one gram.

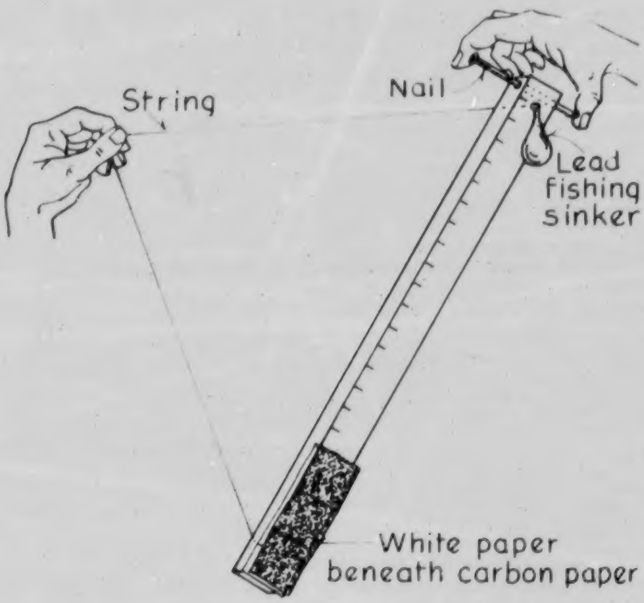
Bring out the ideas that the size of units is not in itself an advantage, nor is one system capable of any greater accuracy than the other. Also stress that both systems are based on arbitrary standards, since the original intention to base the meter on the circumference of the earth was never achieved.

If laboratory scales, calibrated in newtons, are unavailable, any spring balances on hand are easily modified. Since a gram weighs approximately .01 nt., a 200-gm. scale can be used as 2-nt. scale without altering any of its markings. There will be a 2 percent error in making this conversion, but this is within the limits of accuracy of most laboratory spring scales.

1.29. DETERMINING THE ACCELERATION OF FREE FALL

Experiments which attempt to determine the acceleration of gravity during free fall will usually furnish disappointing results unless the apparatus permits time and distance measurements to three significant figures. The small part of a second that elapses as an object falls a reasonable distance in the school laboratory virtually necessitates a release apparatus which is synchronized to an automatic timer. An inexpensive device is described below.

a. Make a timer using a meter stick as a pendulum. Drill a hole through the end of a meter stick parallel to the 1-cm. mark of the scale and place a nail through the hole so that the stick swings freely when suspended. Then attach a string and a lead weight as shown in the diagram below. The period of the pendulum may then be determined by timing a series of swings for approximately 30 to 60 seconds and then calculating the average time that is required for each swing.



To operate the apparatus, hold the string as shown in the diagram. When the string is released, the lead weight will start falling and the meter-stick pendulum will start its timing cycle at the same instant. Since the weight falls vertically, it will collide with the meter stick exactly one-quarter of a period after release. After a trial to determine the approximate position of collision, tape small pieces of white paper and carbon paper to the stick so that the weight will produce a dot at the point of impact. A lead fishing sinker is especially good for this apparatus because it makes a sharp dot.

With the distance and time data available, the acceleration of free fall may be readily calculated using the well-known relationships given in physics textbooks.

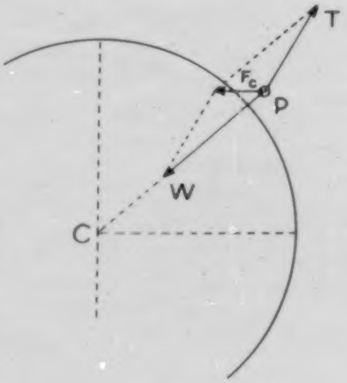
1.30. THE CENTRIFUGE

Use a commercially-produced rotator attachment to show the principle of the centrifuge. The liquid may be a suspension of mud or sulfur. The latter is achieved by adding acid to a solution of hypo and letting the mixture stand for a while. Pour some of the suspension into a test tube at the time the centrifuge vials are filled, and use this for comparison purposes.

Point out that the frictional forces in the liquid are not sufficient to accelerate the more massive particles along a circular path of such a small radius.

1.31. CENTRIPETAL FORCE AND THE PLUMB LINE

A curious consequence of the earth's rotation is that a plumb line in our latitude does not point exactly toward the earth's center. In the diagram, *P* is the plumb-bob, and *W* is its weight, acting toward the earth's center of mass. F_c is the centripetal force necessary to cause *P* to follow a circular path as the earth rotates. Since this must be the resultant of the two forces acting on the bob (its weight and the tension *T* in the cord supporting it) these two forces cannot be in line.

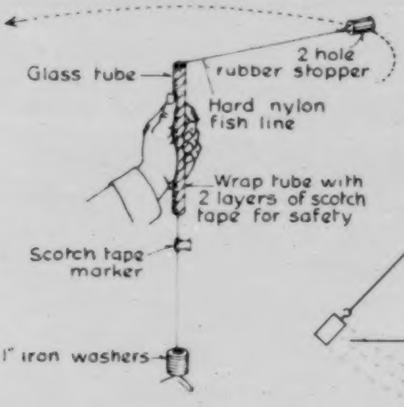


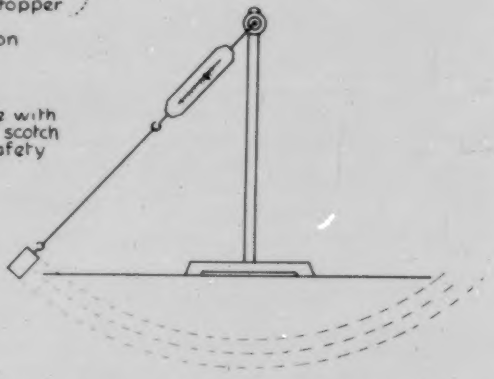
Because of this effect, it might be said that New York's skyscrapers are "leaning" toward the north.

1.32. CENTRIPETAL FORCE MEASUREMENT

a. To demonstrate centripetal force, pass a piece of strong thread about 5 feet long through a 5-inch length of glass tubing, the ends of which have been fire-polished. The thread has a knot or a paper clip attached to it to serve as a reference point. To one end of the thread attach a 100-gm. standard mass, and to the other end a rubber stopper having a mass of approximately 20-gm. Use the tubing as a handle, holding it vertically with the large mass hanging down from the bottom. Start whirling the small mass over your head. As its speed increases, it will lift the larger mass, increasing the radius of its path. Show that at a given radius, marked by the position of the knot or the paper clip, a larger velocity is needed to support a larger weight. As the rotation slows down, the radius decreases since the centripetal force (the large weight) remains the same.

This procedure is satisfactory as a quantitative experiment. Keep the rotation as constant as possible, measure the period, and from that calculate the linear velocity. Measure the radius of rotation by stretching the apparatus out on the table with the knot or paper clip in the same position as when it is in use. While this does not give the actual radius because the thread does not describe a plane, but a cone, the error is negligible. The result of computing the centripetal force from $F = \frac{mv^2}{r}$ should correspond reasonably well with the weight being supported ($w = mg$).





b. As a pendulum swings through its arc, the cord must exert a force larger than the weight of the bob to keep it in its curved path. To measure this centripetal force hang a weight by a cord from a spring balance, and allow the combination to swing as a pendulum. The reading of the balance will be greatest when the mass is at the lowest point in its path. The difference between this reading and the mass of the bob is the centripetal force. If a larger mass is used, the necessary force is increased.

Raising the mass to a greater height before releasing it results in a greater balance reading. The use of a shorter cord for the same height and mass also increases the force. In this way it can be shown that centripetal force depends on the mass, velocity, and radius of curvature of path.

This experiment can yield satisfactory quantitative results. The velocity is computed from the height to which the bob is raised above the lowest point in its arc.

1.33. CONSERVATION OF MOMENTUM

The following demonstration may be used to stimulate an interesting discussion of some of the consequences of the third law of motion.

Place a small electric fan on a skate-wheel cart with the cord trailing. When the fan is turned on the cart will move across the table. If a large card is placed in front of the fan and fastened to the cart, the cart will not move. Ask the students to explain this. Of course, as the fan pushes to the right on the air, the air pushes to the left on the fan. The air also pushes to the right on the card which is fastened to the cart. The two forces acting on the cart are approximately equal in magnitude and opposite in direction.

A small 1.5-volt electric motor fitted with a model airplane propeller may be used in place of the fan. The battery can be mounted on the cart, and the trailing cord can be eliminated. Commercial apparatus of the battery — airplane propeller type is available.

1.34. CONSERVATION OF MOMENTUM USING ACTION AND REACTION APPARATUS

The laws of conservation of momentum may be "discovered" in the laboratory by using a given force to propel two objects in opposite directions and then analyzing their motions. If both objects are allowed to travel for the same time, the distance each covers is proportional to its average velocity.

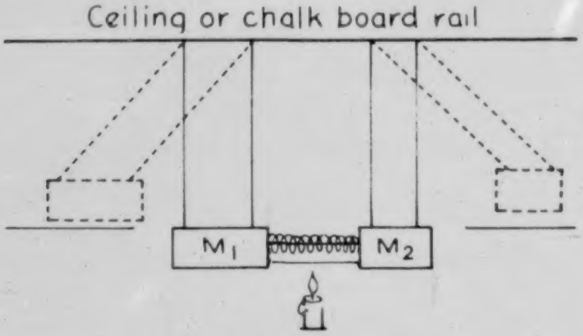
a. Connect two small cars, such as are often used with the inclined plane, or two skate-wheel cars by a long, thin rubber band. Now if they are drawn apart to stretch the rubber band, the rubber band exerts equal and opposite forces on them so that when released they will come together. Cement small pieces of sponge rubber or cellulose sponge to the front of each car to reduce the shattering effect of the collision. Results will be most reliable if the cars are identical and wheel-bearing adjustments and lubrication make the friction in them as nearly alike as possible.

If equal masses are carried by the cars, their point of meeting will be equally distant from the two starting points. If the total mass of one car is twice that of the other, the more massive car will travel half as far as the other before they collide. (The forces are the same except for small differences in friction, and the acceleration must be inversely proportional to the mass. The distance is proportional to the acceleration.) Use upright cardboard indicators on the table to mark the starting points of the cars.

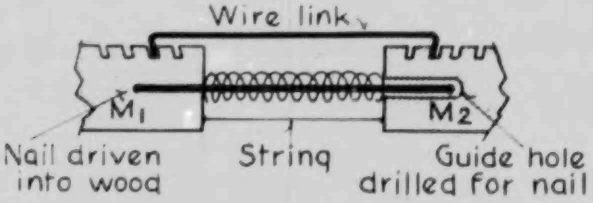
Bring out the point that this might be used as a method of measuring inertial mass, a method which does not involve gravitational force in any way.

Conservation of momentum is demonstrated by comparing the momentum of one car with the momentum of the other car, recalling that the velocities, represented by the distance, are opposite in direction. The initial momentum of the system was zero and the final momentum is also zero if those produced are equal and opposite.

b. Suspend two known masses by strings as shown in the diagram. Cut or burn the restraining cord between them and determine the height to which each rises. The velocity of each mass may be calculated using the relationship $v = \sqrt{2gh}$ from which the momentum (mv) is found. The mass of each object may be varied by fastening small metallic objects to it with a rubber band or tape. The force exerted by the compressed spring may be varied for different trials by using a U shaped wire link that is inserted in appropriate notches to hold the objects together while tying on the restraining string. Once the string is secure, the wire link is removed.

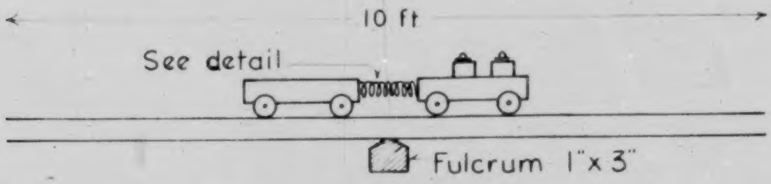


A convenient way to determine the height is to record the angular displacement of a suspension string ϕ and calculate the height from the trigonometric relationship $h = r\ (1 - \cos \phi)$. Details for mounting the compression spring and retaining cord are shown in the diagram below.



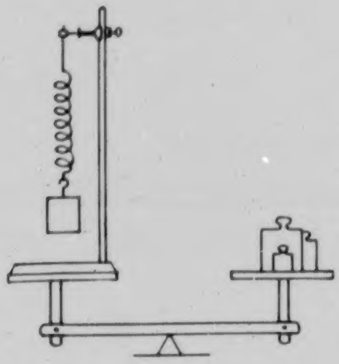
c. Dynamics carts with spring loaded bumpers and trigger release mechanisms can be purchased from scientific supply companies. When the carts are placed on a table with the compressed bumper of one touching the other cart, the compression bumper may be released and the resulting momentum of each cart determined. These carts are quite versatile and can be used for a variety of other experiments related to dynamics and conservation of energy.

For a thought-provoking demonstration, tie two carts together with the spring-loaded bumper compressed as shown in the diagram. Balance the carts at the center of a 3-meter board which is itself balanced on a 5 cm. by 5 cm. fulcrum. Burn the string and have the class observe that the system remains in balance as the carts roll in opposite directions along the board. Adding mass to one of the carts will result in the two carts having different velocities after release but the board will still remain in balance during each trial.



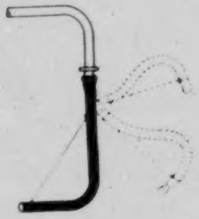
1.35. THE LAWS OF MOTION AND CONSERVATION OF MOMENTUM

To illustrate the laws of motion and conservation of momentum hang a mass from a spring, supported by a clamp on a ringstand. Choose the length and strength of the spring, and the size of the mass for as long a period of oscillation as practical. With the apparatus resting on the desk and the weight bobbing up and down, discuss the part played in the oscillation by inertia of the mass, and the changing forces exerted by the spring on the mass, as its extension changes. When this has been thoroughly discussed, ask the pupils whether the table supporting the ringstand is playing any part in the oscillation. After an expression of opinions, place the apparatus on the platform of a balance designed to handle large masses, and balance it with the mass at rest. Holding the balance stationary, start the oscillation and then release the balance. Explain the result in terms of the forces and also in terms of conservation of momentum.



1.36. WATER JET REACTION

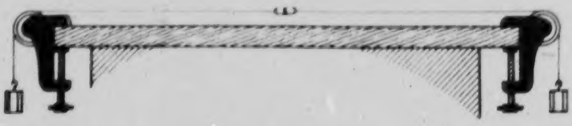
To show the recoil due to a water jet, use a 1-foot length of light, flexible rubber tubing. Tie a piece of string about 6 inches long on the tube at two points, so as to pull it into an approximate right angle turn. Attach the tube to the water faucet and turn on the water cautiously. With the water flowing gently, the tube stands out in a most unnatural position. If the water is turned on hard for a moment, its writhing is most instructive, but will shower water on a good portion of the classroom.



15

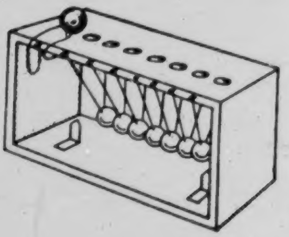
1.37. TENSION IN TUG-OF-WAR ROPE

If equal and opposite forces act on a cord, it is difficult for students to understand that the tension in the cord is the same as either force and not their sum. Clamp a pulley at each end of the front edge of the demonstration table. Hang a 200-gm. weight on the end of each of two pieces of cord, pass the cords over the pulleys and attach them at the center with wire hooks, easily made from paper clips. After suitable discussion as to the tension in the cord, disconnect the hooks and insert a spring balance. Let the class discuss the probable readings of two spring balances, end-to-end between the hooks, and then demonstrate this. Ask what the balance reading would be if one of the weights were replaced by a rigid connection. To try this, attach the spring balance to a clamp fastened at the middle of the front edge of the table.



1.38. CONSERVATION OF MOMENTUM AND KINETIC ENERGY

Make a wooden frame 18 inches long, 12 inches high, and 6 inches wide. Suspend seven steel balls of equal size from the top edges of the frame. (An eighth ball somewhat larger in size may be added later to make the demonstration more complete.) The balls should be at least an inch in diameter or preferably larger. The cord is passed through and knotted on two metal "ears" soldered to the ball. The points of support are screw eyes with two loops of cord taken around the shank, so that the position of each ball can be adjusted by turning the screw eyes from which it is suspended. The positions of the points of support for adjacent balls should be *exactly* as far apart as the diameter of the balls used. If a larger ball is used, suspend it the same way at the end of the line with its points of support a little farther from the others to make up for its greater diameter.



Bore 1-inch holes in a line *part way* through the top; these can be used to hold the balls not being experimented with. Make tabs of cardboard bent at a right angle and cut to a point on top, and high enough so that they *almost* touch the balls. These tabs are used as indicators to mark the positions of the balls at various parts of the tests.

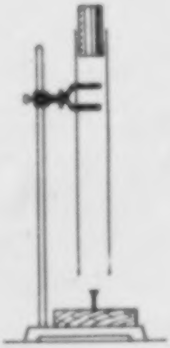
If the large ball is placed on top of the frame, with the remaining ones accurately lined up, and one of the small ones drawn back and allowed to strike the line of balls, a single ball will be driven out from the other side. The impact of two balls will cause two to swing out, and so on.

If all the balls except two adjacent ones are put on the top out of the way, it can be shown that when two equal balls strike, there is an exchange of velocities.

If the large ball is stationary and is struck by the small one next to it, it can be shown that the smaller one does not transfer all its kinetic energy to the large one, but rebounds.

1.39. ENERGY AND THE PILEDRIVER

Potential energy and the work done by a falling object can be shown with a simple device. Drive a nail into a piece of soft wood by allowing a mass to fall on it. The cylindrical brass or steel mass is guided by a large diameter glass tube, or a cardboard mailing tube 2 or 3 feet long. Start the nail straight with a hammer. Measure the original height of the nail and its height after a blow from the falling mass. From the original height of the driver and its mass, compute its potential energy. Using these figures, calculate the force with which the nail resists being driven.



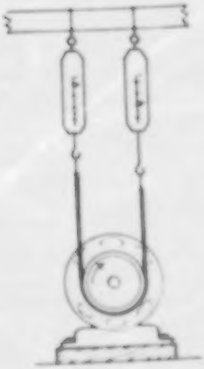
In the discussion point out that this resistance is the force necessary to decelerate the falling mass in the short distance in which it is stopped.

1.40. POWER MEASUREMENT

a. A band brake may be used to measure the horsepower of a motor. The motor to be tested is clamped to the tabletop and has a medium-sized pulley on its shaft. A belt is passed around the pulley and each end attached to a spring balance fastened to a horizontal support beam. When the motor is running, the friction drag between pulley and belt produces a difference in the balance readings. This difference is the force being exerted by the motor at the pulley surface. Use a tachometer or revolution counter and stopwatch to get the motor speed while under load.

The work done per minute (power) is the product of the force, the circumference of the pulley, and the speed of the motor in r.p.m. If the force is expressed in pounds, and the distance in feet, the horsepower can be found by dividing by 33,000 ft.-lbs./min. The initial tension on the belt can be changed by raising or lowering the balance support.

b. Pupils may measure the power they can develop in running upstairs. The work done is the product of the student's weight, the number of stops and the height of the risers. Pupils doing this should be in good health.

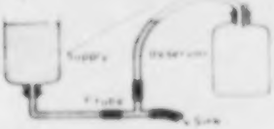


Point out that such a large power (in many cases more than one horsepower) can only be developed by a human being for brief and infrequent periods. Suggest that the same test applied to the stairs of some high building or monument, would prove this conclusively.

1.41. ENERGY AND THE HYDRAULIC RAM

The hydraulic ram may be used as an illustration of inertia and also to help develop energy concepts. Glass models are sold by science supply companies, but a homemade version can be constructed.

Invert a large plastic hypochlorite bleach container from which the bottom has been cut. In its mouth insert a stopper fitted with a bent section of large diameter glass tubing. Couple a glass *T* to this and terminate over the sink with a 3-inch piece of thin-walled rubber tubing. A delivery tube, to deliver water to the reservoir, is connected to the third arm of the *T*.



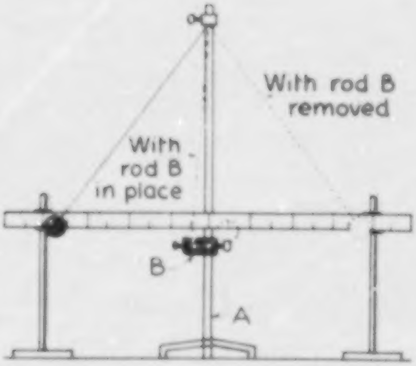
It is essential that there be no constrictions between the bottle and the sink so that flow of water is rapid. Pinch the rubber outlet suddenly and the water rises in the delivery tube. With sufficiently rapid water flow, the level in the delivery tube can be made greater than the supply level, so that some water can be returned to the reservoir.

1.42. CONSERVATION OF ENERGY—GALILEO'S EXPERIMENT

Hang a pendulum from a clamp attached to a vertical support rod, and behind it mount a meter stick which is horizontal. A tightly-stretched horizontal string can be used instead of the meter stick. Show that if a pendulum is started on one side at the level of the meter stick, it will swing as high on the other side, discounting friction losses. Discuss the change from potential, to kinetic, and back to potential energy, making clear their equivalence.

Clamp a horizontal rod *B* to the pendulum support *A*, so that it will project and interrupt the motion of the pendulum to make it swing in an arc of smaller radius. If started at the level of the meter stick, the bob will still swing to the same height.

Ask the pupils to predict the position of this rod where it will force the pendulum to loop around it. Then demonstrate this.



1.43. POTENTIAL AND KINETIC ENERGY

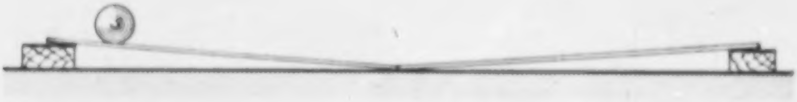
a. The "cum-bak" is an interesting child's toy which can be used to illustrate energy concepts. It consists of a cardboard cylinder containing a rubber band stretched between its ends and along its axis. From the center of the rubber band hangs a weight. When the cylinder is rolled, the weight winds up the rubber band and when the initial kinetic energy has been used, the rubber band unwinds, making the toy come back. When wound up, it will roll up an incline. If slightly wound, and started down an incline, it will gradually slow down to a stop and may reverse itself.

Compare its behavior with that of an identical cylinder in which the weight and rubber band have been replaced by an equal weight of lead shot held in place against one end by paraffin.

b. The familiar yo-yo can also be used to illustrate potential-kinetic energy transformation. Be sure to ask the class the nature of the energy at the very bottom of its path to bring out the fact that kinetic energy is not necessarily linear.

c. A simple pendulum, or a mass, bobbing up and down on the end of a coiled spring can be used as a device in which energy is repeatedly transformed.

d. A double incline can be made of strips of glass and a cylindrical weight allowed to roll back and forth. Glass strips up to 2 feet in length and several inches wide are often discarded by glaziers. The slope of the inclines should be very slight—perhaps 1 in 50. The period of such an arrangement is long enough to permit identification of the various energy states as they occur.



1.44. FLUID FRICTION AND CONSERVATION OF ENERGY

An easy way to illustrate fluid friction is to spin a hard-boiled egg on a smooth surface and compare its behavior with that of a fresh egg spun in the same manner.

If the fresh egg is stopped momentarily and then released, it will resume turning; whereas the hard-boiled egg will not.

1.45. FRICTION

a. Dependence on Normal Force. To show that friction depends on the force pressing the surfaces together, drag a block of wood across the desk at a constant speed with a spring balance. Then load the block by placing a weight on it and measure the friction again at this same speed. If this is done for several values of load, a graph of friction as a function of the normal force should be linear. The coefficient of friction may be calculated by determining the slope of this graph.

An alternate procedure is to slide the wood block along a hardwood board which has been polished to a uniform surface and to exert the force by a mass at the end of a cord passing over a pulley. When the block, once started, slides uniformly on the surface, the weight must be the same as the friction.

b. Starting vs. Sliding. Show that starting friction is greater than sliding friction. Pull horizontally with a spring balance on a loaded wood block resting on the table. Take the balance reading just as the block starts to move, and again when it is sliding steadily.

As an alternate procedure, an incline may be used. Adjust the height of the incline until the block, once started, slides uniformly down it. Also show that the slope must be much greater for the block to start sliding by itself—and that once started, it accelerates. This shows that the force necessary to start it must be greater than the sliding friction.

Stress the importance of these factors in operating a car. There is much less traction on a slippery surface while the wheels are spinning than when they are turning at a low enough speed so that they do not slip. Also, in applying the brakes, friction between tires and road decreases as soon as a skid starts. The greatest stopping force is obtained by a brake pressure just under that which locks the wheels.

c. Rolling vs. Sliding. Slide a cylindrical kilogram weight across the desk top; then turn it on its side, and roll it, to compare the retarding force of sliding friction and rolling friction. Or compare the angles of an inclined plane required to make the cylinder slide or roll uniformly down it. Plan an exhibit of large ball, roller, and needle bearings. These can be obtained inexpensively at automobile junk yards. Point out how these three types of bearings reduce friction.

d. Dependence on Material and Surface.

(1) Measure the friction by the method described in *a* between the woodblock and a wood surface, and compare it with the value obtained by sliding the block across a glass or metal surface. Or change the surface friction by setting the block on a square of paper and dragging it across the original surface.

(2) Show the effect of lubrication by wiping the surface with a light coat of oil and measuring the friction.

1.46. HEAT AS A FORM OF ENERGY

The heat resulting from work can be readily demonstrated:

a. Bend a piece of iron wire back and forth rapidly and feel it to note the rise in temperature.

b. Hold a rubber band lightly against the lips and quickly stretch it, noting the rise in temperature. After it has been held stretched for a few moments, allow it to contract quickly. It will feel cooler as a result of doing work.

c. Draw a heavy nail out of a board, using a claw hammer, and feel its increased temperature.

d. Rub the palms of the hands rapidly together.

e. Pound a piece of lead hard several times and note the temperature rise.

1.47. HEAT EQUIVALENT OF MECHANICAL ENERGY.

Many simple demonstrations can serve to show that mechanical work can be transformed directly into heat.

a. Measure the temperature of mercury in a container, stopper it tightly and shake it vigorously for a minute or so. Transfer of heat from the hand can be avoided by use of an insulating pad. A temperature increase of several degrees can easily be observed.

b. A large smooth-headed nail can be held in the chuck of an electric or hand drill, pressed head down into a shallow hole in a block of wood and rotated rapidly. The smoke which soon arises is an indication of the temperature rise that results.

1.48. THE DISTINCTION BETWEEN TEMPERATURE AND HEAT

Have two beakers containing thermometers and *equal* amounts of water at the same temperature. Pour *unequal* amounts of boiling water into them and compare their temperature changes. Although the added water was in both cases at the same temperature, the larger amount transferred more heat, as evidenced by the greater change in temperature it produced.

1.49. TEMPERATURE INDICATORS FOR DEMONSTRATIONS

Several methods of reading temperatures during classroom demonstrations are available, and each is adaptable to certain situations.

a. *Sensation*. The use of the "human thermometer" has its obvious limitations, but is unexcelled for engaging the attention of a class. Point out the unreliable nature of sensation, perhaps by a demonstration. A student places one hand in hot water, the other in cold. When both are then placed in warm water, one hand reports it as hot—the other as cold. A substance feels cold if the skin loses heat—hot if the skin gains heat. Thus a rough comparison of heat conductivities can be made by feeling two substances, even though they are at the same temperature.

b. Air Thermometers. A Galileo type thermometer has the advantages of visibility and sensitivity. A pair of such thermometers joined by a liquid manometer can be used for comparison purposes.

c. Liquid-in-Glass Thermometers have the serious drawback of being visible to just one observer at a time. When used in a demonstration, it is probably best to call on a student assistant to take such readings, giving the individual some practice, and, in some experiments, convincing the class that the reading is not influenced by the demonstrator's knowledge of what it should be.

d. Dial Type Thermometers with probes, are commercially available, can be read by several persons at once, and are satisfactorily accurate.

e. Projection Thermometers. Both dial and glass thermometers are available for projection. However, this inflexible arrangement calls for a bit too much "staging" to suit the busy teacher.

f. Thermocouples. With a sensitive lecture table galvanometer, a thermocouple can be used to make a most satisfactory demonstration thermometer. Full directions for construction and use are given in Sutton's *Demonstration Experiments in Physics*, p. 195.

g. Thermistors. When projection type meters are connected to a power supply and thermistor, they may be calibrated to give readings that are highly accurate.

h. Other Methods. Temperature sensitive paints are available and can be adapted to certain situations. Pellets and sticks with specific melting points can also be obtained.

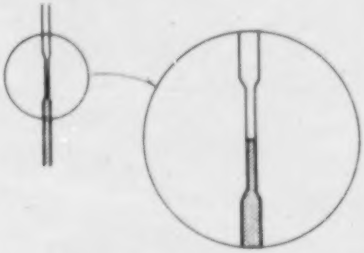
1.50. GALILEO'S AIR THERMOMETER

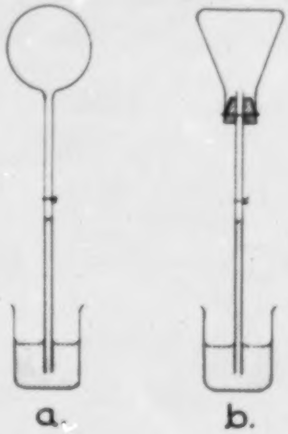
This consists of an air chamber with a tube dipping into a colored liquid. It may be either a bulb blown on the end of a 1-foot length of glass tubing (*a*), or a flask provided with a one-hole stopper and a length of glass tubing (*b*). In either case, support the thermometer vertically with the end of the tube under the surface of colored water in a beaker. Warm the bulb so that air bubbles out. As it cools, the decrease in pressure of the enclosed air allows water to rise in the tube. Get the water to stop somewhere near the middle of the tube.

This thermometer is very sensitive, but has a tendency to "coast" after the heating or cooling influence is removed and it responds to changes in atmospheric pressure as well as temperature.

Tie a piece of string around the tube tightly enough to stay in place, but loosely enough so that it can be moved to a new position. This serves as a marker to indicate the water level.

The response of such a thermometer can be amplified by drawing out a section of the tubing to decrease its bore. Adjust the liquid level so that its surface is in this fine section when the thermometer is at room temperature.





1.51. PRINCIPLE OF THE THERMOMETER

The relative expansion rates of glass and water, and the principle of the liquid-in-glass thermometer should be shown.

Insert a one-hole rubber stopper holding a 10-inch length of glass tubing in a flask *full* of colored water. As the stopper is pressed down, water rises in the tube. Mark the position of the meniscus by tying a piece of string around the tube. Apply heat to the flask. The water level first drops slightly as the glass expands, then rises because of the larger expansion coefficient of water. The effect can be enhanced by drawing out a section of the tube to decrease its bore, as shown.

It is interesting to note the difference in expansion rate of Pyrex and soft glass by comparing the initial drop of the water levels in assemblies using containers of the two different materials.

1.52. CALIBRATION OF A THERMOMETER

The calibration of a blank thermometer is an interesting and valuable experience. These uncalibrated thermometers can be purchased from scientific equipment dealers. Run a piece of sandpaper along one side to roughen it enough to take pencil marks, without impairing visibility of the mercury column. Locate the freezing and boiling points of water in the usual way. Using a metric rule, mark off the space between these points in 10 equal lengths, thus locating intervals 10 centigrade degrees apart. Mark off individual degrees somewhere near the middle of the scale and test the accuracy of the result by comparing its reading with a commercially calibrated thermometer when both are in the same beaker of hot water. Agreement within a degree is easy to achieve.

1.53. COMPARISON OF SPECIFIC HEATS

a. A qualitative demonstration to introduce the topic of specific heat involves the measurement of only a temperature change. Balance empty calorimeters on a platform scale and add equal masses of cool water at the same temperature. Bring equal masses of different metals, for example, lead and brass, to the same temperature in a steam bath, place each in the water in one of the calorimeters and measure the temperature changes.

b. Compare the specific heats of two liquids, for example, water and carbon tetrachloride by dropping equal masses of the same metal, brought to the same temperature in steam, into equal masses of the two liquids, at the same temperature. Compare the temperature changes of the liquids.

c. The general concept of specific heat can be shown by supplying heat equally to two different materials of identical mass, and measuring their temperature changes. Use as the two materials, a block of metal and a beaker containing the same mass of water. Hold the beaker by a clamp and hang the metal object by a piece of wire so that they can be heated by bunsen flames that have been adjusted to be as nearly alike as possible. Show the class that you can still put your fingers in the water when the metal object is so hot that it causes water that is splashed on it to sizzle into steam. Or pick the block off its wire support with forceps and put it in the water in the beaker. The violent boiling shows their difference in temperature.

1.54. MEASUREMENT OF SPECIFIC HEAT

a. A semiquantitative measure of specific heat can be made quickly. On a platform balance, match the weights of two similar calorimeters, each about a third full of cool water and containing a thermometer. Have ready a beaker containing boiling water and the object whose specific heat is to be demonstrated.

Remove the object from the boiling water and quickly place it in a calorimeter. Stir the water and measure the rise in temperature. Then, leaving the calorimeters on the balance, pour boiling water into the other calorimeter until a condition of balance is restored, and measure the rise in temperature. The demonstration can be stopped at this point, showing the difference in the amount of heat delivered to the water in the calorimeters by the two materials, or the figures can be used as a basis for computing the approximate specific heat of the solid.

b. Measure the specific heat of a substance by the standard method of mixtures. For full details, see a laboratory manual.

Perhaps the greatest emphasis in this experiment should be placed on anticipating, and attempting to avoid or counteract, the numerous sources of error. As with other experiments (heat of fusion and heat of vaporization) using this method, a premium is placed on preliminary planning of the best sequence of measurement and timing of the various operations. The largest source of error is due to the difficulty of transferring the object from the boiling water or the steam bath to the calorimeter without either serious drop in temperature or carrying along hot water. The students should realize that these two errors, acting in opposite directions, help counteract each other and cause results to appear to be more accurate than they actually are.

1.55. BOILING

The features observed in raising the temperature of water to the boiling point and in boiling the water are less familiar than most students think. With a bunsen flame, heat a clean glass flask about half full of clear water. Have a two-hole stopper fitted with a thermometer and a short, bent delivery tube in the mouth of the flask. Note the following:

- Almost as soon as heating is started, air, which has been dissolved in the water, forms small bubbles which rise to the surface.

- While the water is being heated, its temperature near the surface is not very different from its temperature near the bottom. Visible evidence of the convection currents can be seen by looking through the water at some bright object on the other side and noting the shimmering.

- Steam bubbles at first form on the bottom and collapse as they come in contact with the cooler water above. The water is not boiling until the steam reaches the surface.

- The temperature of water boiling furiously is the same as when boiling quietly.

- The temperature of the steam above the surface of the boiling water is nearly the same as that of the boiling water. At this point the phenomenon of bumping may be encountered. The water ceases to boil for a few seconds, then bubbles of steam rise violently to the surface. The temperature of the water rises above its boiling point while it is quiet, and drops sharply when the steam bubbles form.

- The steam in the flask and at the end of the delivery tube is invisible. The cloud that is often called "steam" is really a cloud of water droplets.

- Steam bubbles increase in size rapidly as they rise in the water in contrast to the negligible change in size of air bubbles.

One fairly safe, but unspectacular way to show the rise in boiling temperature with increase in pressure is to deliver the steam to the bottom of a tall hydrometer jar filled with water. The water in the flask must be boiling hard. The collapse of the steam bubbles when they enter the cold water in the jar is instructive.

Add salt or sugar to the boiling water to show the resulting increase in boiling temperature. The sudden increase in the rate of boiling when the material is first added is due to the formation of steam bubbles on the sharp edges of the little crystals.

1.56. COMPARATIVE COOLING EFFECT OF ICE AND ICE WATER

The topic of heat of fusion can be introduced with a qualitative demonstration.

Balance empty calorimeters on a platform balance. Add equal masses of warm water at the same temperature. Then drop some chopped ice into one of the calorimeters, and an equal weight of ice water into the other. Compare the temperature changes of the contents of the two calorimeters.

1.57. COOLING THROUGH THE FREEZING POINT

a. Observe the changes in temperature of a substance as it cools from the molten condition through its freezing point to the solid phase. The substances usually used are acetamide or naphthalene. Sodium acetate and hypo also serve the same purpose. Put the crystals and a thermometer in a test tube and melt the substance with a bunsen flame or a hot-water bath. If using the flame directly, move the flame back and forth along the test tube so that the contents are heated uniformly and slowly. Be careful not to heat the contents of the tube to a temperature higher than the thermometer can safely stand. Allow the test tube and its contents to cool, taking periodic temperature readings. Draw a graph of the result, noting and explaining various features of the curve, such as undercooling, the plateau during solidification, and the difference in slope of the liquid-cooling and solid-cooling portions of the curve.

b. This familiar and valuable experiment is usually done by using some crystalline substance with a melting point well above room temperature. (See *a*.) The use of such a material suffers from several disadvantages—the worst of which is that students have great difficulty in relating mentally the behavior of the solidifying substance to the similar events which take place when water freezes. The fact that acetamide has two different melting points is a confusing issue when that material is used, and the high temperature required to melt these materials is a hazard to equipment.

It is suggested here that the same experiment be performed, using the water-to-ice change. A beaker contains crushed ice with about 30 ml. of alcohol poured over it. The temperature of this mixture will remain at about—15°C. A small test tube containing water and a thermometer stands in the beaker. The water level should be a little higher than the level of the freezing mixture. Adjust the position of the thermometer so that it can be read with a minimum of handling. With moderate care undercooling can be observed. When the temperature has dropped to about—5°C., lift the test tube from the freezing mixture and trigger the freezing by shaking, stirring or dropping in a small piece of ice. The formation of frost on the beaker and the depression of the temperature of the ice by the addition of alcohol are interesting and valuable additional observations.

One of the most useful outcomes of this experiment is achieved by drawing and analyzing the extremely informative temperature-time graph of the results.

1.58. HEAT OF FUSION OF WATER

The usual method of mixtures can be used to measure the heat of fusion of water. See a laboratory manual for details.

Of the large number of possible errors in this experiment, the one which has the greatest effect on the result is the addition of water to the calorimeter along with the ice. Since this error is very difficult to avoid, and produces a result lower than the accepted value, any result which is too high is usually a signal of gross error in measurement of computation. Taking the ice at the last possible minute, using chunks rather than chips or shavings, drying it, and avoiding handling it with the fingers are precautions which will increase the final accuracy.

1.59. COOLING BY EVAPORATION

a. Take the temperature of a volatile liquid—alcohol, ether or carbon disulfide—while it is in the bottle, to show that it is not appreciably different from room temperature. Then remove the thermometer and watch its indication drop as the liquid on the bulb evaporates. Using a small piece of cloth, such as psychrometer wick, around the bulb increases the effect.

b. Ethyl chloride is used by physicians to produce local anaesthesia by cooling. This volatile liquid can be purchased in drug stores. It is usually sold in a small bottle, fitted with a valve and jet nozzle. The rapid evaporation of ethyl chloride and the resultant intense cooling can be demonstrated by squirting a small amount of liquid on the students' hands.

c. The cooling effect of evaporation can be demonstrated to a class by use of an hydrometer. Swab one of the bulbs with alcohol or any other volatile liquid. Fanning both bulbs produces cooling in the moistened bulb and no result in the other.

1.60. COMPARATIVE HEATING EFFECT OF STEAM AND BOILING WATER

A qualitative demonstration serves to introduce the concept of heat of vaporization. Balance empty calorimeters on a platform balance. Add equal masses of cool water at the same temperature. Take temperature readings to show that steam and the boiling water from which the steam is evolved are at essentially the same temperature. Allow steam to bubble into cool water in one of the calorimeters until several grams have been added, and measure the rise in temperature. Then add an equal mass of boiling water to the other calorimeters and measure its temperature change. Compare the two to show that the steam supplies more heat than the boiling water at the same temperature.

1.61. HEAT OF VAPORIZATION

a. This is a simple but rather inaccurate method of measuring the heat of vaporization of water. It is capable of yielding a result of the right order of size without use of the methods of calorimetry.

Assume that a flame or heater delivers heat to a flask of water at a constant rate. Measure the time required to raise the temperature of a known mass of water from an initial temperature to the boiling point. Compute the number of calories per second delivered to the water. Allow the water to boil for 2 or 3 minutes, noting the exact time, and then reweigh to determine the mass of water vaporized. Knowing the rate of transfer of heat and the time, the total heat involved in vaporizing the water can be calculated. From that figure and the mass of steam, the number of calories required to vaporize a gram of water can be determined.

Various refinements of this procedure can be applied in order to improve the accuracy of the result.

b. The standard laboratory procedure for measuring the heat of vaporization of water uses the method of mixtures. See a laboratory manual for complete details.

Results in this experiment are generally lower than the accepted value. Use of a trap to prevent entry of water with the steam helps to reduce the error. Students generally underestimate the heating effect of steam, and allow the calorimeter temperature to rise too high, producing an error in the same direction.

1.62. KINETIC MOLECULAR THEORY

Students are helped in forming a concept of the molecular nature of matter by information about sizes, distances and speeds of molecules. This also is a good opportunity to teach the handling of very large and very small numbers by use of powers of 10. For convenience, some of the numerical information is given here.

Size: Most gas molecules such as those composing air are about $2-4 \times 10^{-8}$ cm. in diameter. More complex molecules are of course much larger.

Distance apart: Under normal conditions, gas molecules are about 3×10^{-7} cm. apart. This can be made graphic by holding two spheres at a proportionate distance from each other; ping-pong balls, for example, about 50 cm. apart. Of course, this figure is an average value, the distance constantly changing as the molecules move from collision to collision.

Velocities: At normal temperatures, the average velocities of molecules of nitrogen and oxygen are about 4×10^{4} cm./sec. This is comparable to the speed of a rifle bullet, or the speed of sound in air. At any instant in a gas there is a wide distribution of velocities, ranging from some molecules that are barely moving to others which are traveling with many times the average speed. As the tmmperature is increased, the average molecular speed increases, and also the number of molecules traveling at a very high speed.

Distance between Collisions: The mean free path of air molecules at standard conditions is about 9×10^{-6} cm. Thus they travel about 300 times their diameter between collisions. A molecule collides with others about 5×10^{9} times a second. As air is pumped out of a container, the distances between molecules, and their mean free path both increase. Television picture tubes must be highly evacuated so that the mean free path of electrons within the tube is comparable with the length of the tube, otherwise the electron beam would be diffused by collisions with gas molecules.

Numbers of Molecules: A cubic centimeter of gas at normal conditions contains about 3×10^{19} molecules. Even in a space which is highly evacuated an incredible number of molecules must remain. If the pressure were reduced to one billionth of atmospheric pressure there would still be 3×10^{10} molecules in each cubic centimeter.

Liquids and Solids: In liquids the molecular motions are somewhat similar to those in gases, although the molecules are much closer together. The physical difference between liquids and gases is due to the fact that in liquids the distance between molecules is so small that the attraction between them does not permit them to move freely between collisions. In solids the molecules have more or less fixed positions and the motion of each is confined to a definite space.

1.63. MOLECULAR BOMBARDMENT

Add about a half inch of mercury to a Pyrex test tube and float a dozen or so tiny chips, cut from a splint or other soft wood, in the mercury. Connect the test tube to a vacuum pump and evacuate. With the pump running, heat the mercury carefully. Soon the chips of wood will begin to dance in the test tube as they are repeatedly struck by mercury molecules, although there is no apparent disturbance in the mercury itself. Point out the high velocity of the mercury molecules necessary to produce so sharp a reaction, and also the fact that the dancing of the wood chips is increased by a rise in temperature, showing that the velocity of the molecules is increased by increase of temperature. Illuminate the tube well for best visibility.

1.64. BROWNIAN MOVEMENT

Brownian motions are best viewed individually. Draw smoke from an extinguished match into a cell which can be placed on the stage of a microscope. Such a cell is produced commercially. Illuminate it intensely from the side. Sunlight or converging light from an arc is best. Use a low magnification to look at the suspended smoke particles. They are seen to be in constant, haphazard movement, as a result of impacts by air molecules.

Be sure that students do not think they are looking at molecules, or that the swirling caused by convection currents in the cell is the Brownian motion.

With a little more preparation, the same effect can be observed in a liquid suspension. Very dilute India ink, or a gamboge (graphite particles in alcohol) suspension are recommended.

1.65. DIFFUSION OF GASES

The diffusion of gas molecules can be shown by a demonstration which is assembled at the beginning of a class and observed every now and then during the period. Use a 2- or 3-foot length of large diameter (about 1.5 inch) glass tubing in a horizontal position. Wet a wadded filter paper with ammonia and place it in one end; and place in the other end a piece of filter paper wet with hydrochloric acid. Cork both ends. With a tube three feet long, reaction becomes apparent in about 10 minutes and the ammonium chloride deposit between ends is quite dense in half an hour. This ring is fairly well localized, nearer the acid than the ammonium hydroxide, illustrating the greater diffusion rate of the less massive molecules. The inclination of the ring is caused by the fact that the ammonia molecule is lighter than air, the hydrogen chloride molecule more dense.

I.66. CHARLES' LAW AND ABSOLUTE ZERO

A Charles' Law tube can be used to obtain data for demonstrating the relationship between the pressure and the volume of a gas. This device is a capillary tube, closed at one end, with a bead of mercury in the bore near the center. As the tube and the air in it are heated, the motion of the mercury indicates expansion of the air. The length of the air column is proportional to its volume, permitting a quantitative experiment. Many laboratory manuals describe such an experiment. However, these are generally directed at a measurement of the coefficient of expansion, rather than at the more fundamental concepts of the linearity of the relationship and the location of absolute zero. The following procedure is suggested:

a. Make measurements of the air volume at several temperatures between 0°C. and 100°C.

b. Show by means of a graph that the relationship between volume and temperature is linear.

c. Show by extrapolation that there is an intercept on the temperature axis at which the volume would be zero if the gas behavior remained unchanged while it was being cooled at that point. This temperature should, of course, be absolute zero, —273°C.

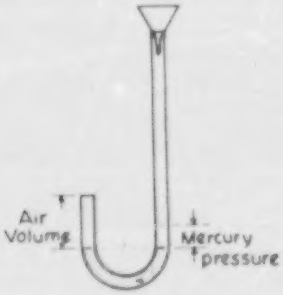
The relatively small span over which the temperature can be controlled and the necessary extrapolation make this an inherently inaccurate experiment. Several sources of error can be minimized. The air being tested must be dry. The entire length of the air column must be immersed in the constant temperature bath. The tubing must be as uniform in bore as possible.

A refinement involves tying the thermometer directly to the tubing and using the thermometer graduations as a scale to measure length as well as temperature. The use of standard diameter glass tubing is possible if it can be kept horizontal throughout the experiment.

1.67. VARIATIONS OF GAS VOLUME WITH PRESSURE

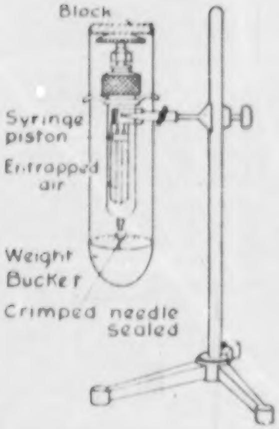
Quantitative demonstrations which show that the volume of a gas varies inversely with the applied pressure are comparatively easy to set up and provide data which lends itself to graph analysis. Three types of apparatus which have been used successfully are described below:

a. Into a J tube that is sealed at the short end, pour a sufficient amount of mercury to fill the bottom. The difference in heights of mercury in the two arms of the J tube is proportional to the mercury pressure on the trapped air. Small quantities of mercury are added to the open end of the tube and readings of the relative mercury pressure and the air column height are recorded with each addition. This technique is well known and is described in many texts and lab manuals, but because the mercury is rather expensive and easily spilled, the technique below might be more suitable for individual laboratory exercises.



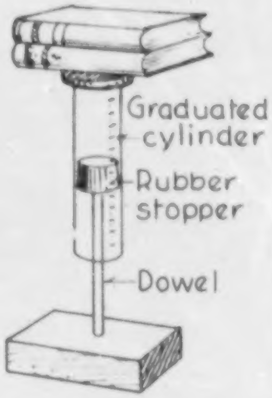
b. A hypodermic syringe requires very little modification for use as a Boyle's Law apparatus. A recent law permits the use of these devices for educational purposes providing certain procedures are followed. School administrators should obtain the necessary information from the Bureau of Science Education of the State Education Department before syringes are purchased.

Close the opening in the hollow needle by crimping it and then applying solder. If binding is a problem, lubricate the plunger with some light lubricating oil such as that used for sewing machines or typewriters. Experience has shown that heavier oils are good lubricants but cause excessive binding and that stopcock grease is not satisfactory as a plunger seal. Stopcock grease, however, will insure a good seal between the bottom of the syringe and the needle. Using these oil and grease seals it is possible to vary the pressure from about 0.5 atmosphere to 1.5 atmosphere without leakage.



Pressure may be applied to the plunger in a variety of ways. One way is to drape a plastic or leather sling over the plunger and add weights to a container as shown in the diagram. Adding standard masses in 200-gm. increments should provide approximately 10 readings within apparatus limits.

d. Use a 50-ml. or a 100-ml. graduated cylinder as a gas container and apply pressure by means of a snug fitting piston. To make the piston, insert a large rubber stopper as far as it will go into the cylinder and cut off the part of the stopper that protrudes. Fasten the end of a dowel stick to the stopper and mount the apparatus as shown in the diagram. Books placed on top of the apparatus provide pressure to compress the trapped air. To minimize the effects of friction between the piston and the cylinder wall, use glycerine for lubrication and be sure to measure the height of the air column both as books are added and also as books are removed. To ensure that the trapped air is at atmospheric pressure when the piston is first inserted, provide a path for air to escape by using a small wire between the stopper and the piston wall. When the starting position has been reached, hold the apparatus horizontally to prevent any pressure on the enclosed air and carefully slide out the wire.



WAVES

2.01. SETTING UP A "SLINKY" FOR DEMONSTRATIONS

An excellent way of demonstrating the characteristics of waves is to use a flat coiled spring. Although any coiled spring will serve, particularly good results are obtained when a spring similar to an inexpensive child's toy, known as a "slinky," is used. The laboratory "slinky" is considerably longer than the toy and may be stretched to approximately fifty times its closed length without suffering from permanent distortion. Even at this tension, it will work satisfactorily. Pulses may be shown by simply stretching the "slinky" out on the floor. However, the energy is rapidly lost through friction. Friction may be reduced by suspending the "slinky" in air with every fifth or sixth coil supported by a string. A "slinky" set up in this manner may be used to demonstrate the phenomena described in 2.02.

It is recommended that the science teacher consult with the building superintendent or custodian before attaching any apparatus to the ceiling. In some cases eyebolts can be spot-welded to support girders in such a way that maximum strength can be obtained with a minimum disturbance of the ceiling symmetry.

A rod, or taut table, 15 or 20 feet long, near the ceiling may be used to mount the "slinky." If the strings are fastened to the rod with curtain rings, the "slinky" may be collapsed when not in use. The strings should be at least five feet long. Select a spacing (e.g., every 5 coils) and use it consistently when tieing the strings to the spring.

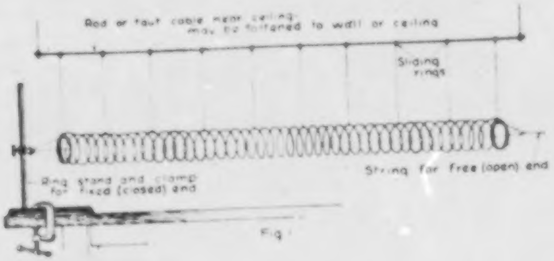

Rod or taut cable near ceiling; may be fastened to wall or ceiling
Sliding rings
String for free (open) end
Ring stand and clamp for fixed (closed) end

Fig. 1

To keep the "slinky" extended, horizontal force must be applied to each end of the coil. For a fixed end, the coil may be clamped to a post or a ring stand which has been fastened to the lab table, or it may be held in place by hand. For a simulated free end, attach a string which is at least half the length of the extended "slinky." A large piece of cardboard, held near the middle of the spring may be used to damp the vibration.

NOTE TO TEACHERS:

— If you suspend from a cable it must be very tight. Turnbuckles may be used to tighten it.
— When collapsing the "slinky" do it slowly. If it is allowed to snap back the coils may become inextricably intertwined.

If you cannot fasten a support to the ceiling or walls, the setup diagramed in figure 2 may be used. Because of shorter strings waves of smaller amplitude must be used. In addition, students may have difficulty seeing the demonstration.

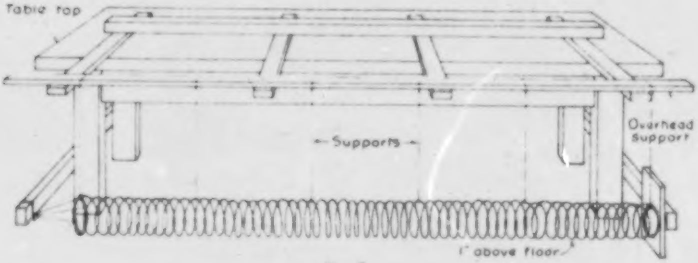


Fig 2.

2.02. PULSES AND PERIODIC WAVES ON A "SLINKY"

NOTE TO TEACHERS:

This activity may be done as a demonstration with the "slinky" set up as described in 2.01, or as a laboratory exercise. If the students do this as a laboratory exercise, they will probably have to use the "slinky" on the floor. The attentuation resulting from friction will make some of the phenomena a little more difficult to observe. However, since there is no substitute for direct laboratory experience, it is suggested that the activity be carried out both as demonstration (using the setup described in 2.01) and as a laboratory exercise. In the laboratory, students may work in groups of three or four.

Pulses

Students should learn that a pulse is a single vibratory disturbance which moves from point to point. Since generation of a smooth pulse requires a little practice, one partner should hold the end of the "slinky" while it is stretched to about 30 feet on a smooth floor and the other may practice generating pulses by quickly moving the end of the spring horizontally to one side and back to the original position. Students will note that when the vibration is perpendicular to the direction in which the pulse is propagated it produces a *transverse* pulse. A *longitudinal* pulse is made by quickly moving one end of the spring parallel to the length of the spring and back to the rest position. Have students compare the direction of vibration to the direction of propagation. Transverse pulses are easier to observe.

With one end of the "slinky" held so it is not free to move, send a pulse from the other end. Can students determine if the speed or shape of the pulse seems to change?

Send another pulse down the right side of the "slinky." Which side of the spring is the reflected pulse on? Hold one end of the "slinky" with a string about one-half the length of the "slinky." A "slinky" tied in this way has an "open end." Send a pulse down the right side of the "slinky." Compare the pulse reflected in this case with the one reflected by the fixed one.

Have students determine the speed of a pulse. If you allow the pulse to go back and forth a few times you can increase the accuracy of the measurement. Change the tension on the "slinky" and measure the speed of the pulse again. How was it affected?

As a pulse travels down the "slinky," what happens to the maximum displacement of points on the spring (amplitude)? If there is a change, what accounts for it?

Can students predict what will happen when pulses are sent from both ends of the "slinky" and on the same side at the same time? What will occur if they are sent on opposite sides?

How does the maximum displacement of the spring at the point where the pulses meet compare with the maximum displacement of each of the pulses?

Have students send pulses of the same size on the same and opposite sides of the "slinky." What happens?

Periodic Waves

Periodic waves may be produced by vibrating one end of the "slinky" horizontally about a rest position. If this is continued long enough, the wave reflected at one end of the spring will combine (or "interfere") with the wave traveling away from the generator, (hand). Try varying the frequency and see if students can produce a standing wave. What are the limits on the frequency and/or wavelengths of standing waves produced?

2.03. SUGGESTIONS ON THE USE OF RIPPLE TANKS

Most of the fundamental concepts about waves may be developed through experimentation in a ripple tank. Ripple tanks and ripplers are commercially available or may be constructed as described in 2.04 and 2.05. (A complete ripple tank and rippler is available for less than $25.00).

Tips on the Use of Ripple Tanks

- It takes a little time to learn how to use a ripple tank. Teachers should get their ripple tanks operating and acquire prior experience before the students use them.
- Several laboratory periods will be required to do the basic ripple tank experiments. If you have your lecture in the physics lab, the students will be able to work with the tanks for several days (perhaps a week) in a row.
- Students should level the tanks carefully at the start of each laboratory period. Check the depth of each corner and make necessary adjustments.
- Unless otherwise specified, use a depth of from 5 mm. to 7 mm.
- Make sure the tank is well supported to prevent extraneous vibrations which may cause the generation of anomalous waves.
- Some of the tanks, which use a wooden frame, tend to develop leaks which can be resealed with caulking compound.
- It may be helpful to show some of the 8-mm. ripple tank film loops in conjunction with these experiments.
- In general, as soon as they complete an experiment, students should start the next experiment so that valuable laboratory time may be conserved.

2.04. CONSTRUCTING AND SETTING UP A RIPPLE TANK

The tank itself can be made of window glass to which wood strips, about 1-inch by 1-inch are secured with aquarium cement or a good grade of tile mastic cement. A window set in its frame and caulked to make it waterproof can serve as an excellent tank. In many demonstrations you will want to put up "beaches" along the sides of the tank in order to prevent unwanted reflections. These beaches can be made of wire mesh covered with bandage gauze. For most demonstrations the water depth should be 5 mm. to 7 mm. Provision should be made for supporting the tank horizontally on its own legs, although a pair of straight chairs may be used.

A straight filament 50-watt or 200-watt lamp may be used for illumination.

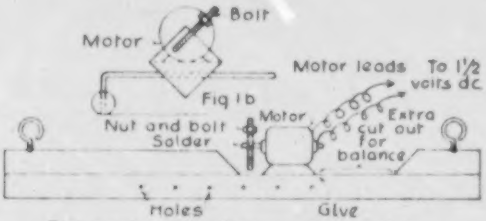
The lamp may be placed in a metal housing made from sheet metal or in a fruit juice can. A point source of light may be approximated by cutting a 2-inch diameter hole in the side of the bulb housing.

Waves may be projected onto the floor as illustrated or the light source may be reversed and the wave patterns observed on the room ceiling or on a screen suspended above the tank in a light wood frame.

2.05. RIPPLE TANK WAVE GENERATOR

NOTE TO TEACHERS:

Commercial versions of the wave generator are available at low cost if the teachers prefer to purchase them.



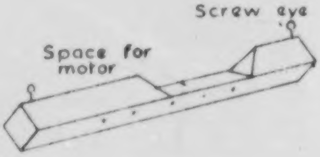
End view with pt generator in place

Materials list:

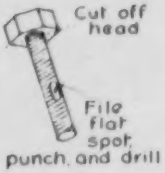
The following materials are required to construct a ripple tank wave generator:

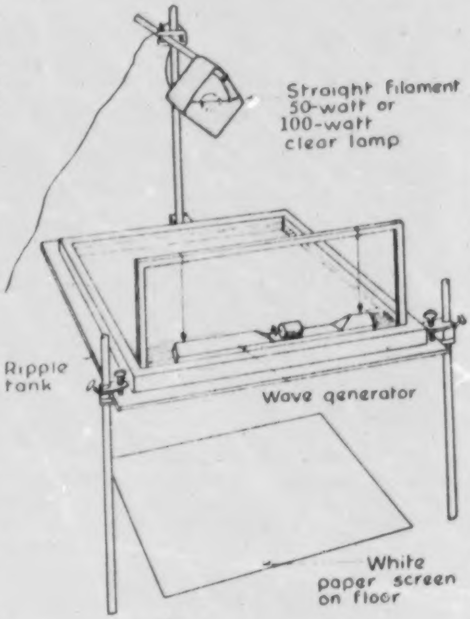
Wood:	1 inch by 1 inch by 14 inches
Motor:	$1\frac{1}{2}$ - 6 volts, D.C. midget
Rubber bands:	about two dozen
Bolt:	brass, $\frac{1}{4}$ x $2\frac{1}{2}$ inches long, with nut (fine thread is preferable)
White glue	
Wire:	two pieces, 8 inches long (from coat hanger)

Wire:	two pieces, 24 inches long, No. 22 copper insulated
Beads:	two plastic, $\frac{1}{2}$ inch or more in diameter ("pop togethers" from the dime store)
Screw eyes:	two, $\frac{1}{2}$ inch eye


Screw eye
Space for motor

Hold the wooden stick horizontally on one edge and cut out 3 inches of the top middle section. This is to form a level space for mounting the motor. Drill vertical guide holes at each end and place a screw eye in each hold. The rubber bands that support the generator will be attached to these screw eyes. Find a drill the size of coat hanger wire (or use a short length of coat hanger wire for a drill) and drill six holes horizontally just below the middle as shown in the illustration. Space them about 1-inch apart. These holes are to hold the point source generators. Cut off the head of the brass bolt; file a flat spot in the middle; make a punch mark; drill a hole large enough for the motor shaft to penetrate. Slip the bolt over the motor shaft and solder it in place being careful to leave plenty of clearance for the nut to turn down to the motor shaft. Screw the nut onto one end of the bolt. The nut serves to adjust the amount of unbalance and therefore the amplitude. It should be turned all the way in for high frequency or the whole tank assembly may vibrate. Two nuts may be used for extra amplitude at low frequency. Nuts


Cut off head
File flat spot, punch and drill


Straight filament 50-watt or 100-watt clear lamp
Ripple tank
Wave generator
White paper screen on floor

can turn easily enough for finger tip adjustment without danger of flying off during operation. Spread white or other waterproof glue on the underside of the motor base and on the wood where it is to set; put motor in place and hold it with rubber bands. The brass bolt should be at the center of the stick and the motor shaft would be aligned parallel with the stick. Allow the glue to set 12 hours. When the glue has set, remove the rubber bands and tie a thread around the free end of the bolt. Suspend the assembly by this thread to test it for balance. If the stick does not hang level, cut away some wood from the top edge of the heavy end until balance is attained, this adjustment is not critical. Solder the lengths of copper wire to the motor terminals. Convert the wires to loose coils by wrapping them around a pencil, then removing the pencil and stretching the wires. This increases the compliance of the wires so they will not restrict the vibration of the generator. Cut two 8-inch lengths of coat hanger wire and taper each end slightly with a file. Bend a right angle curve into one end of each so the tip hangs down about 1-inch. Using again a drill the size of coat hanger wire, enlarge the holes in the beads half way through and push one bead onto the curved end of each wire. These are the generators for circular waves. Loop together two strings of 12 rubber bands each 2 feet long and fasten one string to each screw eye.

Suspend the generator over the ripple tank as shown in the drawing. If the rubber bands going over the edges are objectionable, they can go through screw hooks and down the same side of the ripple tank or through holes near the top. The height and position of the generator can easily be adjusted by sliding the rubber bands one way or the other across the top of the ripple tank support. A convenient method is to adjust the bottom edge to $\frac{1}{4}$ inch above the water, then push it into the water where it will be held by the surface film. The depth is not critical, but it should not touch the bottom at high frequencies. The sides of the generator should be well-wetted in order to obtain a good straight wave. A 10-ohm wire-wound potentiometer gives satisfactory speed control when the motor is run from a 1.5-volt battery.

When point sources are needed, insert the bead-tipped wires into the horizontal holes. The desired separation may be obtained by twisting the wires in the holes. If the beads are both on the same side of the generator, they will act in phase. For a 180° phase shift, one bead may be placed on the opposite side of the generator and the drive set farther out into the middle of the tank.

2.06. CIRCULAR AND STRAIGHT PULSES IN A RIPPLE TANK

NOTE TO TEACHERS:

This exercise is a good introduction to the ripple tank. The experiment is quite simple and should take less than a period. However, it will take students some time to get their tanks working properly so be sure to allow enough time. This is best accomplished by a "guided trial and error" method. If you have a double period, and students finish early, have them start working with the periodic wave generator. Very few, if any, will complete both 2.06 and 2.07 in one double lab period, but the experience will be invaluable, even if no measurements are taken.

Generating Pulses

Set up the ripple tank as directed. The depth of the water should be from 5 mm. to 7 mm. Level the tank by checking the depth at the corners. Be certain that your light source is adjusted so that it acts as much like a point source as possible.

Hold an eye dropper near the surface at the center of the tank and generate a pulse by allowing one drop of water to strike the surface. Observe the image of the pulse on the screen. If it is not clearly defined, you may have to readjust the lamp. Describe the pulse. From its shape what may be inferred about the speed of the pulse in all directions?

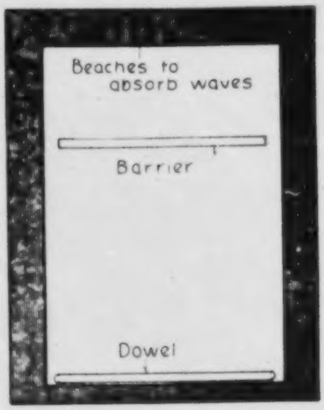
A piece of wood dowel almost as long as the tank and placed parallel to one side can be used to produce a straight pulse by quickly rolling it a fraction of a revolution toward the opposite side of the tank. Describe the pulse. If the dowel is moved too slowly, the pulse will be too weak to show up well. If it is moved too rapidly, the ends of the pulse will be curved. Practice making straight pulses until you can make ones that give good images on the screen.

With the eyedropper, generate circular pulses on the axis of the parabola starting near the surface and moving gradually away from it. Relate the observations to the law of reflection. Good mathematics students will enjoy trying to prove, mathematically, that the law of reflection predicts the observed effects.

Reflection of Pulses

Place a straight barrier in the tank as shown in Figure 1. A piece of wood, or several wax blocks may be used. Generate a pulse that will move perpendicularly to the reflector.

Students should develop the concept that the angle between the perpendicular to the wave front (direction in which the incident pulse is traveling) and the normal (perpendicular) to the reflective

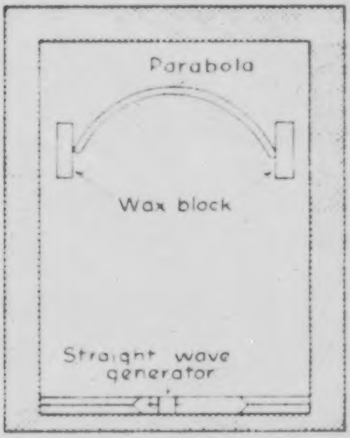


Reflection from a barrier in a ripple tank surface at that point is called the "angle of incidence." The angle between the direction in which the reflected pulse is traveling is called the "angle of reflection."

Change the angle of incidence. Compare the angle of incidence to the angle of reflection. The relationship between the angle of incidence and the angle of reflection can be determined by this method.

Try using a point source of waves and have pupils predict the nature of the waves that will be reflected from the straight barrier.

Substitute a length of rubber tubing for the straight reflecting barrier. The rubber may be bent into different shapes to produce a variety of reflection patterns which converge at focal points.



Extension:

Have students reflect pulses from different shaped surfaces.

A circular pulse generated at the center of a circle and a circular pulse generated at the focus of an ellipse form interesting patterns.

2.07. VELOCITY, FREQUENCY, WAVELENGTH

Set up the ripple tank and level it as in 2.06. Set up the straight wave generator according to the instructions supplied by the manufacturer or as described in 2.05. Be sure that the wave generator bar is in the water to a uniform depth. The water should be from 5 mm. to 7 mm. deep.

Turn on the generator and by adjusting the rheostat, generate waves of several different frequencies. It may require some experimentation with the wave generator bar before you are able to generate waves which show up well on the screen.

Set the wave generator for a low frequency. Look at the projected wave pattern through a hand stroboscope. Determine the least number of revolutions per second which will "stop" the pattern and multiply by the number of open slits. This is the frequency of the wave.

With the wave pattern "stopped" as above, make two marks on the screen, parallel to the waves, several wavelengths apart. Determine the wavelength of the projected waves. (The distance covered by one bright and one dark band.) Make several determinations of the frequency and wavelength. Calculate the speed of propagation using the relation $v = f\lambda$.

Do the waves, as projected on the screen, have a longer wavelength than the waves in the tank? Are the frequencies the same or different? You may determine the "scaling factor" by placing an object of known length in the tank.

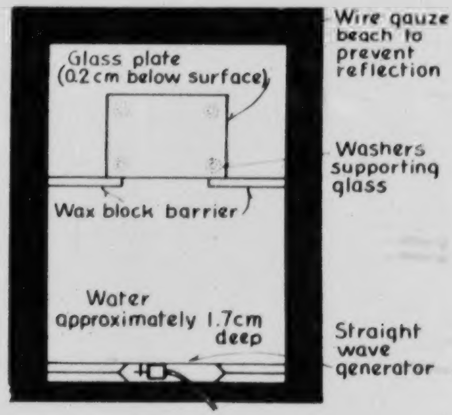
Increase the depth to about 2 cm. and measure the speed of the projected wave. Be careful not to change the relative position of the light source, tank and screen. How is the speed related to the depth?

Place a barrier in the middle of the tank, parallel to the wave generator, adjust the frequency until a stationary pattern is produced by the superposition of the incident and reflected waves. This is called a standing wave. Compare the distance between two adjacent bright bars in the standing wave to the wavelength of the traveling wave.

2.08. REFRACTION OF WATER WAVES

If you did 2.07, students know that the speed of water waves depends upon the depth of the water. In the range in which you are working, as the depth increases, speed increases. This is most apparent at low frequencies of 5-10 cps.

Set up the ripple tank and straight wave generator as in 2.07. Place a glass plate in the tank as shown in Figure 1. The glass


Wire gauze beach to prevent reflection
Glass plate (0.2 cm below surface)
Washers supporting glass
Wax block barrier
Water approximately 1.7cm deep
Straight wave generator

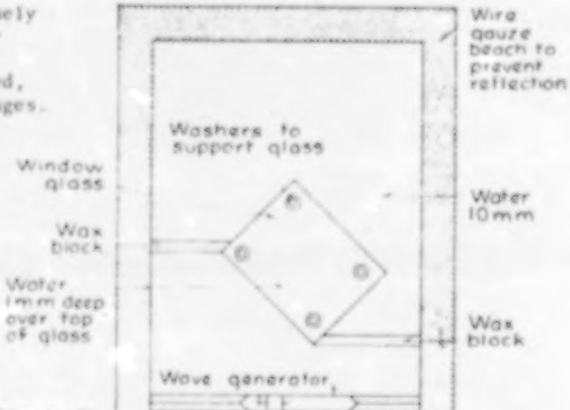
(Figure 1)

plate should be at least 1.5 cm. above the bottom of the tank and the depth of the water above the glass should be not more than 0.2 cm.

Assuming the speed of the waves is less in the shallow water over the glass than in the deep water in the rest of the tank, have students predict what will happen to the wavelength as the wave passes from deep to shallow water. What will happen to the frequency?

Start the generator at a low frequency - about 5 cycles/sec. Is the prediction confirmed?

Turn the glass plate so that the edge is not parallel to the waves, (figure 2). Turn on the generator, and keep the frequency constant. When a wave passes obliquely through a boundary and there is a change in its speed, its direction changes. It is *refracted.* The direction of a refracted wave is stated in terms of the angle of refraction - the angle between the direction of travel of the refracted wave - and the noraml extended.



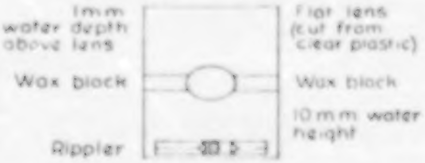
(Figure 2)

Compare the angle of incidence to the angle of refraction. Try several other angles of incidence. Notice what happens when the wave passes the second boundary, from the shallow (low speed) to the deep (high speed) areas. Point out the relationship between the change in speed and the change in direction.

NOTE TO TEACHERS: (This extension may be done when lenses are studied.)

EXTENSION

Cut convex and concave lens from sheet plastic, the lens curvature can merely be arcs of a circle. The parts that remain from cutting the convex lens may be used for the concave lens. Set the "lens" in the water on stacks of washers. Place wax barriers against each end of the lens to block waves as in Figure 3. The water depth on the "lens" is 1 mm., or slightly less. Start the wave generator at a low frequency. Observe the focusing of the refracted waves to the focal point of the "lens." Use the concave lens to produce the diverging pattern formed by the refraction caused by a concave lens.


1mm water depth above lens
Wax block
Rippler
Flat lens (cut from clear plastic)
Wax block
10 mm water height

(Figure 3)

2.09. DISPERSION OF WATER WAVES

NOTE TO TEACHERS: If laboratories are scheduled on a double period basis, this experiment may be done as part of 2.08.

Set up the ripple tank as illustrated in 2.08. Start the wave generator at a low frequency and observe the refracted wave. Gradually increase the frequency. The refraction will increase with the increasing frequency, and students may infer that the difference between the speed of the wave before refraction and after refraction will be greater. This property of differential refraction as a function of frequency can be used to separate waves of different frequencies.

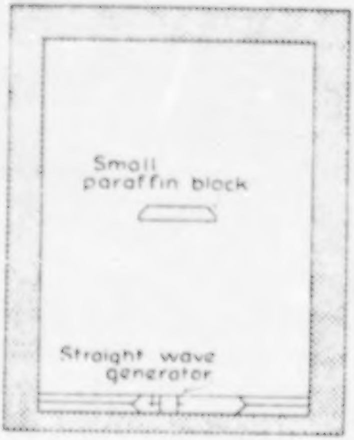
A medium in which the speed (and therefore the amount of refraction) depends upon frequencies is called a "dispersive medium." The separation of waves of different frequencies as they enter a dispersive medium obliquely is called dispersion.

2.10. DIFFRACTION

Set up the ripple tank as in 2.08 and 2.09. Turn on the generator and make sure you can generate good straight waves over a range of frequencies. At the higher frequencies, it is essential that the generator have smooth edges. If the pattern becomes distorted at high frequencies, smooth the edge of your generator and make sure there are no bubbles on it.

Turn on the generator and adjust for a long wavelength (low frequency). Place the end of a pencil in the tank in front of the generator. Does the pencil cause a "shadow" in the wave pattern or do the waves bend around it? [Try to determine the presence of the pencil by observing the pattern at the far end of the screen.] Stand a smooth paraffin block, about 2 cm. to 3 cm. wide, in the tank as shown in the diagram on the next page. The ends of the block should be cut to form 45° angles with the face. Turn on the generator and adjust for a low frequency (long wavelength). [Call attention to the waves as they pass by the block.] Note carefully the ends of the wave near the block. This spreading of a wave into a region behind an obstruction is called diffraction.

Gradually increase the frequency and call attention to the wavelength and the pattern. At high frequencies it is easier to see the pattern by looking at it through a stroboscope with all slits open. If the block casts a sharp shadow in the wave pattern in the ripple tank, it could be inferred that the wavelength is greater than the width of the obstacle.



Place a row of paraffin blocks across the tank leaving a narrow opening or slit in the center. Start the straight wave generator and observe the pattern behind the slit. What kind of source might produce such a pattern? Increase the width of the slit. What happens to the pattern? Set the blocks for a narrow slit again and gradually increase the frequency. What happens to the pattern?

2.11. INTERFERENCE PATTERN PRODUCED BY TWO POINT SOURCES

When two or more waves pass through the same point, at the same time, they interfere with one another. The magnitude of the disturbance may be predicted by application of the principle of superposition. That is, the resultant disturbance is the algebraic sum of the disturbances due to the individual waves. Sometimes, a consistant interference pattern is produced. Standing waves are one example of such a pattern. Two adjacent point sources in a ripple tank produce an interference pattern which has important physical applications.

Set up the ripple tank and place two point sources about 5 mm. apart, on the wave generator. (See the manufacturer's suggestions or 2.05.) Describe the resulting pattern. The points where the waves from the two point sources cancel (points of little or practically no disturbance) are called "nodes." Lines formed by joining adjacent nodes are called nodal lines. Points of maximum disturbance are called antinodes.

Increase the frequency. What happens to the pattern? Does the number of nodal lines increase or decrease?

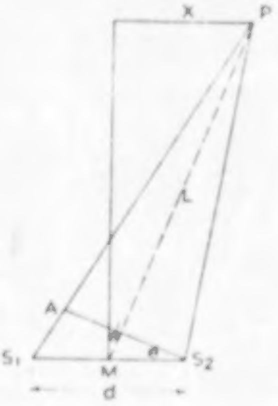
From the principle of superposition, we know that at any given node the crest from one source must arrive at the same time as the trough from the other. That is, along nodal lines, the waves from each source must be one-half wavelength out of phase. Therefore, if the wavelength and the distance between the sources is known, the location of the nodal lines may be predicted.

In figure 1 at the right:

P = a point on a nodal line
S_1 and S_2 = the sources

d = distance between sources
m = midpoint between sources
x - distance from P to point on $\perp$ bisector of S_1S_2

L = distance from P to m



NOTE: The ripple tank analogy for two source interference is only a model. In order for θ to be equal to θ', the sin θ must equal sin θ'. Thus, S_1P must be parallel to S_2P. This means that the ratio of L to d must be in the order of $\frac{10^4}{1}$. In actuality, P represents a point on a nodal line such that an asymptote to the line at point P will, when extended, pass through point M.

Since point P is a node, the distance PS_1, must be $\frac{1}{2}$ (or $1\frac{1}{2}$ $2\frac{1}{2}$ etc.) wavelengths longer than PS_2. We indicate this by writing $(n - \frac{1}{2})\lambda = PS_1 - PS_2$. It can be shown that, if L is large compared to d that $(n - \frac{1}{2})\lambda = d\frac{x}{L}$.

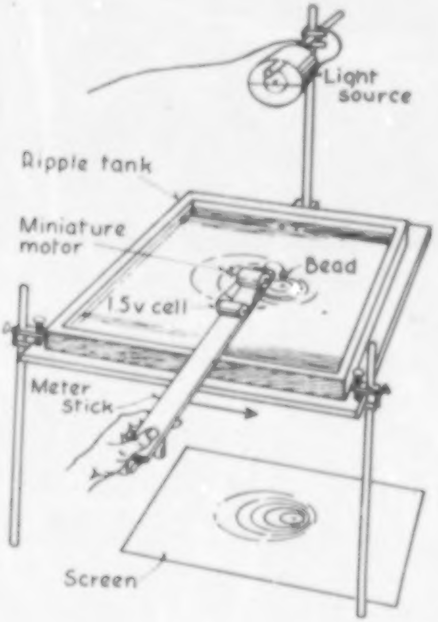
Students interested in mathematics may wish to develop a proof for this. The derivation can be found in elementary college texts and in some modern high school physics textbooks. The statement is sometimes written $(n - \frac{1}{2})\lambda = d \sin \theta$. It should be clear that the $d \sin \theta$ (or $d\frac{x}{L}$) represents the path difference $(PS_1 - PS_2)$. Write an equation which gives the location of the points of maximum displacement.

2.12. THE DOPPLER EFFECT

Method One

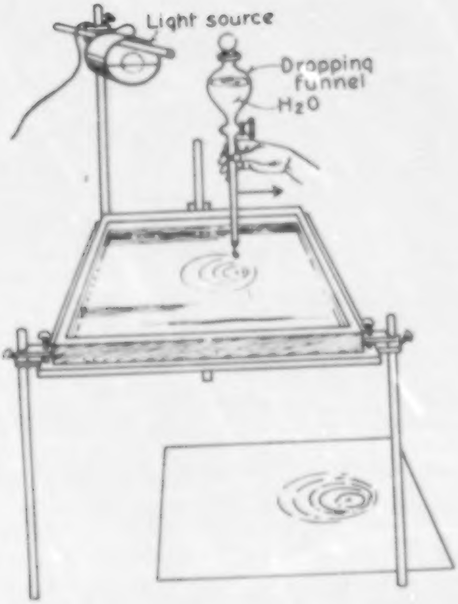
Set up a ripple tank and point wave source as shown in the illustration. Hold the meter stick so the bead of the rippler just touches the surface. Start the motor and slowly move the meter stick across the tank. You will see a projected image of Doppler waves on the screen below the ripple tank.

Point out the increasing frequency or shorter wavelengths on the leading edge of the moving wave as indicated by the squeezing together of the waves in the image. Also point out the lower frequency and longer wavelengths at the trailing edge where the waves are farther apart.



Method Two

A dropping funnel may be used as a source instead of the rippler on a meter stick. Adjust the funnel so that a drop falls every half second. Move it across the water with the drop hitting the surface without causing turbulence. As you move the funnel you will see the droppler pattern projected beneath the tank.

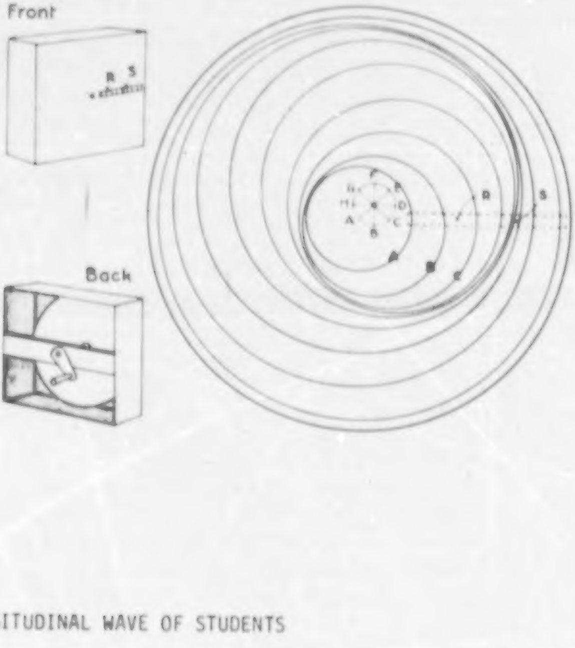


2.13. ALTERNATE METHODS OF DEMONSTRATING WAVE MOTION

This device is a simple and vivid demonstrator of the fundamentals of longitudinal waves. It consists of a plywood or masonite disk marked with a series of eccentric circles. This pattern is viewed through a slot in a screen in front of the disk. When the disk is rotated, the visible portions of the circles move in a fashion that simulates the motion of the particles in a medium transmitting a longitudinal wave. Compressions and rarefactions appear and the vibratory nature of the motion of particles is apparent. Frequency, wavelength, and displacement can all be demonstrated.

The disk should be about 2 feet in diameter. The method of drawing the pattern on it is indicated in the diagram. The smallest circle with a radius of $\frac{3}{4}$ inch, is for construction purposes and should not appear on the finished pattern. Locate points *A*, *B*, *C* etc. on this circle 45° apart. The circles of the pattern are centered successively on these points; that is *A* is the center of circle *A*, *B* of circle *B* etc. Circle *A* should have a radius of $1\frac{1}{2}$ inches and each succeeding circle should be 1 inch greater in radius than the one before it. Nine circles are necessary to complete a cycle and more are desirable. In the diagram, *S* is a compression and *R* a rarefaction. The background of the disk may be white and the circles painted on it in black, using much heavier lines than shown here.

The slot in the white screen is about $\frac{3}{4}$ inch wide and extends from near the center to a point opposite the rim of the disk. For convenience the screen may be part of a simple box of plywood, a handle being provided on the shaft of the disk for ease in turning.



2.14. LONGITUDINAL WAVE OF STUDENTS

A row of five or six students is asked to stand, face the rear of the room, each one placing his hands on the back of the one in front of him. The instructor then pushes sharply on the back of the first one in line and a longitudinal wave proceeds along the line to the last one. Of course, as with any longitudinal wave, energy should not be added to the wave in transit. Common sense precautions should be observed to insure that the receptor is not damaged by the "shock wave."

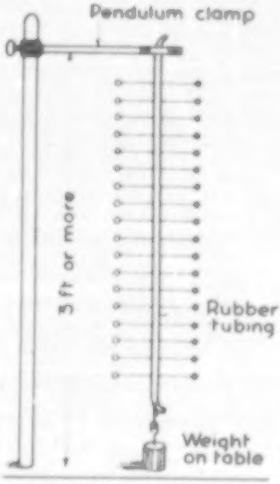
2.15. TRANSVERSE WAVE IN A SPRING OR RUBBER TUBE

Rubber tubing or a coiled spring will serve as a medium for the demonstration of transverse waves. Sashcord or clothesline can be used but is much less satisfactory. In any case, it should be as long as possible and loosely stretched horizontally. Filling the tube with water and clamping both ends increases its weight per unit length, causing the wave to travel more slowly. The wave is produced by striking the "medium" a sharp blow near one end. A light metal object fastened at the other end and dangling against the support will make a clatter at the instant of arrival of the wave, emphasizing both the transfer of energy and the definite time interval required for the wave to travel the length of the tube. The reflection of the wave should also be noted.

2.16. TORSIONAL WAVE DEMONSTRATORS

A device for producing torsional (or twist) waves can be made of rubber tubing, stiff wire and wooden beads. The length of the tubing will depend on the height of the available support, but should not be less than 3 feet. It is convenient to hold it at the top with a pendulum clamp and at the bottom with a weight resting on the table top. Six-inch lengths of stiff wire or rod are pushed through punctures in the tubing 2 or 3 inches apart, taking great care to keep them in the same plane and perpendicular to the tube. Wood balls or beads are mounted on both ends of each wire, all on the side to face the class being black, the other white. The weight on the bottom holds the tubing in a slightly stretched condition, and since it rests on the table does not permit that end of the apparatus to rotate.

To produce a pulse, move the bottom ball sharply to one side and back. The pulse will travel up the line of balls, reflect from the top and return. A wave train is made by moving the bottom ball back and forth steadily. The inverse relationship of wavelength and frequency can be made clear. With some practice, standing waves can be produced and the idea of harmonics in vibrating strings and air columns developed.



2.17. SPEED OF SOUND DEPENDS ON MEDIUM

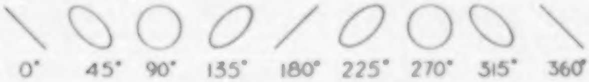
A whistle is operated from the fuel gas supply through a long rubber tube. While there is still air in the tube, the pitch of the sound is normal, but when the gas reaches the whistle the pitch rises sharply. The tube is removed from the gas jet and the demonstrator blows through it. The pitch drops suddenly when his breath reaches the whistle.

After a class has learned of the factors determining the frequency of a tube, this demonstration may be shown without explanation, challenging the students to apply their knowledge to the new situation.

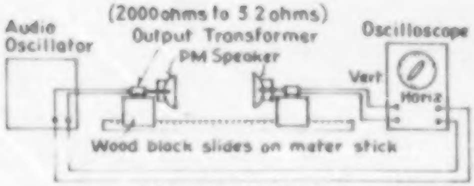
2.18. SPEED OF SOUND USING AN OSCILLOSCOPE

Measuring the speed of sound by the method described below utilizes the phase method of measuring wavelength and serves as a preliminary lesson in the interpretation of Lissajous patterns.

Mount permanent magnet speakers and output transformers on wooden blocks as shown in the diagram.


0°
45°
90°
135°
180°
225°
270°
315°
360°

LISSAJOUS PATTERNS


(2000 ohms to 3.2 ohms)
Audio Oscillator
Output Transformer
PM Speaker
Oscilloscope
Vert
Horiz
Wood block slides on meter stick

APPARATUS SETUP

Speakers having cones from 3 to 6 inches in diameter are suitable. It is preferable to have matching output transformers with the impedances shown in the diagram, but slight mismatches can be tolerated. Provide rails or a groove in the bottom of the wooden blocks so they can slide along a horizontal meter stick lying on a table.

Connect an audio oscillator to one of the speakers and to the horizontal input terminals of an oscilloscope. Connect the other speaker to the vertical input terminals of the oscilloscope. The speaker at the left side of the diagram produces a sound wave and the other speaker acts as a microphone. Set the oscilloscope for external sweep operation and allow the equipment to warm up for a few minutes. After warmup, set the oscillator for about 500 cycles per second and turn up the volume until an audible tone is heard on the loudspeaker. Adjust the horizontal and vertical gain controls on the oscilloscope so that the height and width of the patterns are the same. Move the speakers apart until the Lissajous pattern on the oscilloscope has shown a phase change of 360°. Typical Lissajous patterns and the associated phases of the sound waves are shown in the diagram.

Each time the distance between the speakers is changed by one wavelength, the Lissajous pattern will change through a complete cycle. Use the average wavelength and the frequency indicated on the oscillator dial and calculate the speed of sound using the relationship $V = F\lambda$.

2.19. LENGTH OF RADIO WAVES

Students should be given the opportunity to compare radio and television signals, and determine the similarities and differences of their wave patterns. A comparison of wavelengths can be made and students may be able to chart or graph the wavelengths used by local radio and television stations. These could be illustrated on an expanded chart of the electromagnetic spectrum. Students might wish to compute the number of waves per kilometer.

2.20. THE DOPPLER EFFECT — PITCH SHIFT

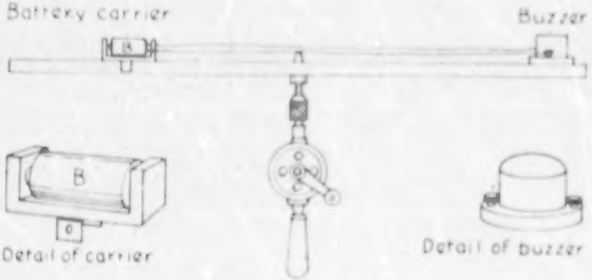
a. Any high-pitched source of sound that can be moved quickly toward or away from a class can be used to illustrate the Doppler effect. A whistle at the end of a 6-foot piece of rubber tubing can be sounded while swinging it in a horizontal circle, or a small loudspeaker producing a high-pitched sound can be swung quickly at arm's length toward or away from the pupils. Difficulties with making the change of pitch apparent can usually be laid to reflections from the walls of the classroom and it is possible to minimize this interference by finding an optimum position in the room for doing the experiment.

b. A mechanical analogy can be used to clarify the phenomenon. On a heavily traveled highway the frequency of passing cars is a maximum when the observer travels against the traffic (moving toward the "source"), less when he is standing still, and a minimum when moving in the same direction as the traffic.

2.21. DOPPLER EFFECT USING A REVOLVING BUZZER

Drill a hole at the center of a meter stick, place a bolt through the hole, and fasten it with a nut and lockwasher. Clamp the protruding end of the bolt in the chuck of a hand drill or a laboratory rotator. Fasten a buzzer near one end of the meter stick and balance it by taping a battery near the other end. Connect the battery and buzzer with wire and bend the tension spring of the buzzer slightly to give it a higher frequency. When the hand drill or rotator is operated at slow speeds, the buzzer will revolve and the characteristic pitch variations characteristic of the Doppler effect will be heard.

A simpler arrangement is to operate a buzzer at the end of long flexible leads and swing it by hand as a pendulum toward and away from the listeners.



2.22. ORIGIN OF WAVES IN VIBRATING MATTER

Any of the following demonstrations can be used to show that an object producing a sound is vibrating.

a. The tips of the prongs of a sounding tuning fork are dipped in water. A low-frequency fork, vibrating strongly produces a visible effect.

b. One prong of a vibrating fork is touched to a hanging pith ball.

c. A commercial stroboscope can be used to show the vibrations of a tuning fork, or the sounding fork can be viewed through a motor driven slotted disk.

d. A siren disk is operated, pointing out that the puffs of air through the holes set the surrounding air into vibration.

e. A toothed wheel, commercially available as Savart's wheel, or a discarded gear is turned by a rotator and a card held against the teeth.

f. A 78-r.p.m. phonograph record is rotated on a turntable and a thumbnail or plastic ruler held in the groove. Fragments of a broken record and hand lenses can be distributed to show that the groove is wavy and causes the sounding object to vibrate.

g. A loudspeaker is connected through an amplifier to an audio oscillator, and the equipment is adjusted to produce a low-pitched tone of large amplitude. The loudspeaker rests horizontally on the tabletop with its exposed cone up. Several pith balls, on being dropped onto the speaker, are batted about by the vibrating cone.

2.23. SENSITIVE FLAME AND TRANSFER OF ENERGY

There are many versions of a flame sensitive to sounds. Construction details are given in Sutton's *Demonstration Experiments in Physics*, p. 162, or Richardson and Cahoon's *Teaching General and Physical Science*, p. 321.

The simplest arrangement is made by drawing a piece of glass tubing to produce an orifice less than a millimeter in diameter. This jet is connected to the gas supply with a rubber tube and the emerging gas ignited. Both the gas pressure and the diameter of the jet are critical factors in causing the flame to be sensitive. The flame should be tall and quiet when undisturbed. The diameter of the orifice can be increased by filing it gently with a fine file. If filing is continued past a sensitive situation, continued filing will bring about another. Repeated tests should be made while filing by jingling a ring of keys or blowing a high-pitched whistle.

Such a flame can be used in place of a microphone and oscilloscope to detect sounds in interference patterns, standing waves or reflections. It is most sensitive to very high pitches such as hissing sounds, scuffing feet on the floor, jingling of keys and the like. When critically adjusted, it will respond to speech, obeying the sharply spoken word "down" for example. Another interesting stunt is to "blow" it down from across the classroom. Its response is to the sound of the blowing rather than to the air, as can be shown by blowing in a direction away from the flame.

2.24. TRANSMISSION OF SOUND THROUGH A MEDIUM

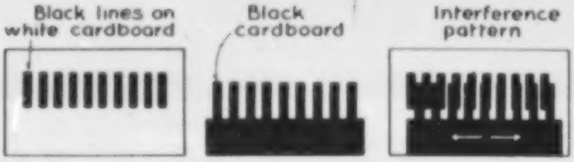
A bell jar with an opening in the top is provided with a stopper fitted with two electric leads. An electric bell hangs from one terminal by a rubber band, and connection is made to the bell by flexible lengths of fine wire. With the bell jar on the pump plate, before being evacuated, the bell is clearly audible. This illustrates, incidentally, that the medium transmitting the sound does not actually move from source to hearer. As a vacuum is produced, the sound of the bell becomes fainter, and when the bell jar is thoroughly evacuated the bell is not audible.

If the special bell jar is not available, an alarm clock on a sponge rubber pad can be used as the source of sound.

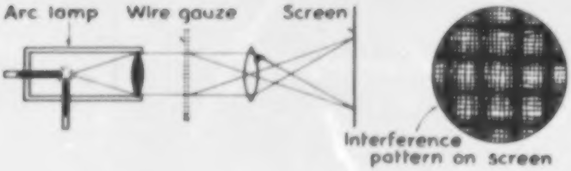
A large bottle containing a small "jingle bell" supported on a rod extending from the stopper may be evacuated through a hole in the stopper. The bell is rung by shaking the bottle.

2.25. INTERFERENCE ANALOGY WITH POCKET COMBS

An interference pattern can be produced with two combs of differing coarseness, or without projection by a pattern of lines on a cardboard poster and a comb-shaped cutout of black cardboard.


Black lines on white cardboard
Black cardboard
Interference pattern

2.26. INTERFERENCE ANALOGY WITH PROJECTED MOIRE PATTERNS


Arc lamp
Wire gauze
Screen
Interference pattern on screen

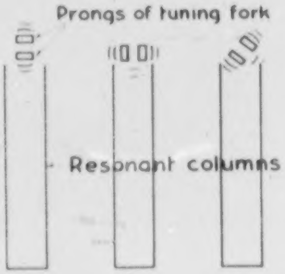
a. Two pieces of wire screening of slightly different mesh are held one over the other and their shadow image is projected on a screen. The number of wires to the inch in the screening corresponds to the frequency of a wave, and since the two screens are of slightly different frequencies, periodic constructive and destructive interference shows up in their combined image. Using two narrow strips of wire gauze and overlapping them for half their width will show the individual frequencies on each side of the interference pattern. A third piece of gauze different in mesh from either of the others permits forming a different beat frequency.

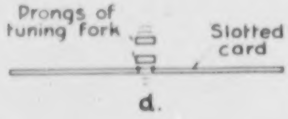
b. Prepare a master by constructing a set of concentric arcs, about 1 cm. apart centered near the edge of an 8½-inches by 11-inches sheet of paper. Use this to make at least two transparencies for use on the overhead projector. If positive transparencies are used, when they are placed on top of each other, with the centers about 2 cm. apart, the nodal lines will appear as a series of dots on the screen. The center of the arcs represent the sources and the pattern may be altered by changing the distance between the centers. This type of interference model is called a Moire pattern.

2.27. INTERFERENCE IN SOUND OF TUNING FORKS

The sound produced by an unaided tuning fork is weak because it is the sum of waves emerging from both prongs and from the space between. These waves interfere in all directions and effectively cancel along four lines. This can be demonstrated by slowly rotating a sounding tuning fork near the ear. For purposes of class demonstration, the fork should be rotated over an air column tuned to be resonant at the frequency of the fork. In the diagram the fork is viewed end-on. In positions such as *a* and *b*, the tube will respond normally, but when the fork is inclined as at *c*, no response will be heard.

This interference can be greatly reduced by mounting a slotted card in front of one prong of the fork as in *d*. The slot should be about the same size as the fork. Placing the card in position makes the sound from the fork much louder.





2.28. INTERFERENCE OF SOUND WAVES

Couple a small speaker with a long flexible dual conductor to an audiofrequency oscillator, using an amplifier if necessary. Set the frequency fairly high, say 3 to 6 kc./sec. Move the speaker about the front of the room to shift the pattern of interference between direct waves and those reflected from the walls. The class can hear these changes in volume. With the speaker stationary on the desk, move a large sheet of poster board behind it. At specific distances the sound will be louder and at other distances much weaker, as the reflected wave is in and out of phase with the direct wave. Bending the cardboard slightly to make a concave reflector enhances the effect. Moving the speaker toward and away from the chalkboard produces a similar effect.

Couple two similar speakers to the same source, hold one in each hand—at arm's length, and slowly turn, to move the interference pattern around the room.

An interesting and extremely instructive addition to these experiments is to place a microphone in an empty seat in the classroom. Connect it to a cathode-ray oscilloscope in view of the class. Each member of the class can then compare his sensation with what would be heard by a student occupying the seat with the microphone, and the existence and motion of a definite pattern is apparent.

Produce an oscilloscope pattern with one or two sources - pass the microphone across the classroom to show positions of maximums and minimums.

Using two speakers, and with the microphone connected to the oscilloscope in front of them at a position of destructive interference, disconnect one of the speakers and see the signal increase. *CAUTION: Reflections and any increase in loudness of the remaining speaker may mask this effect.*

Several other arrangements can be used to demonstrate interference between direct and reflected sound. Using a single speaker and microphone at opposite ends of the desk, move the cardboard screen back and forth behind the speaker. Place the screen to one side of, and parallel to, the line connecting the two, and move it back. Simulate the fading of a distant radio signal by using the screen to represent the ionosphere and varying its height between speaker and microphone.

Show diffraction of sound waves by placing the screen between the two, with its bottom edge resting on the tabletop. High frequency sounds will not pass around it. However, as the frequency is decreased, the signal received increases.

Place a speaker about 2 meters away from a flat reflecting surface. Use a microphone connected to an oscilloscope to explore the space between the speaker and screen for the nodes and antinodes of standing waves. If the position of the microphone is measured for a series of consecutive nodes, the wavelength of the sound can be calculated. Use this wavelength and the known velocity of sound in air at the temperature of the room to calculate the frequency. Compare the result with the dial setting of the oscillator.

2.29. THE PRINCIPLE OF BEATS USING PHASED PENDULUMS

The process of two periodic events of different frequencies getting in-and-out of step with each other can be shown by using pendulums of different lengths. The two pendulums are suspended, one behind the other, as viewed by the class and started together. It can be shown that the frequency of their being in phase (the beat frequency) is the same as the difference in frequency of the two individual vibrations.

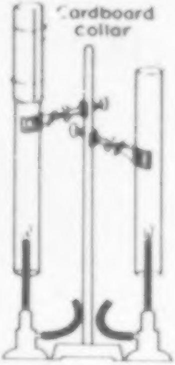
2.30. AUDIBLE BEATS

Audible beats can be produced by two musical sounds which are close, but not identical in frequency.

a. Plastic dime store whistles are seldom in tune. Blow two at once to produce beats.

b. The frequency of a tuning fork can be shifted slightly by loading one or both prongs with rubber bands. Two identical forks, one of them thus loaded will produce beats when sounded together.

c. Two "singing tubes" can be used. This arrangement has the advantages of loudness, of producing sustained sound, and of being controllable in pitch while in operation. The tubes are about 3 feet long and $1\frac{1}{2}$ inches in diameter. They are clamped vertically, and one or both provided with a collar of light cardboard, so that their lengths can be changed. Each tube has a bunsen burner projecting into its lower end. The burners are lit, using small flames, the tubes lowered over them, and the height of each flame and position of each tube with respect to its burner adjusted for loud clear sound. Show:



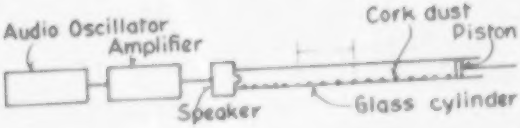
- That when the pitches are the same, no beats are heard.

- That when the collar of one tube is moved to change its pitch, beats are heard.
- That the frequency of the beats is related to the difference in pitch.
- The process of tuning one form from a pitch lower than the other to a pitch that is higher.

d. Show that production of beats is not exclusively a characteristic of audible sounds by using a radio and an R.F. signal generator. Tune the radio just off the frequency of a strong station so that the program is not distracting. Couple the signal generator to it in any convenient way. Usually a short length of wire attached to the output terminal of the signal generator and lying on the bench near the radio is sufficient. Tune the signal generator past the frequency of the broadcast station, explaining the resulting beat note and its changing frequency.

2.31. STANDING WAVES

a. In a glass cylinder. A novel variation of the standard Kundt's tube demonstration uses an audio oscillator, amplifier and speaker connected as shown in the diagram below.



Place some cork dust in a glass tube. Press the cone of the speaker against one end of the tube and close the other end with a stopper or piston. When the speaker operates, standing waves will be set up and the cork dust will accumulate at the nodes which space themselves at half-wavelength intervals along the length of the tube. Changing the frequency of the oscillator will cause the cork dust to be rearranged in the tube. This may be shown to large groups using an overhead projector. Driver units for outdoor loudspeakers (approximately 25 watts) are especially suited for this demonstration because the part which delivers the sound fits nicely into the end of the glass tube and can be sealed with tape. These drivers are available at electronic supply stores. [Large discarded fluorescent tubes with the ends cut off and the inside cleaned may be used for the demonstration. According to the manufacturers, the fluorescent tubes which have been manufactured in the past few years are perfectly safe and no longer contain the toxic powders which their predecessors had.]

The wavelength is equal to twice the distance between two nodes. If the frequency of the oscillator is known, the velocity of sound can be determined using the relationship $V = F\lambda$.

b. In a current carrying conductor. Standing waves may be demonstrated by stretching a wire carrying an alternating current between the poles of a magnetron magnet. These magnets may be obtained from supply houses which sell surplus equipment.

Stretch a wire between the poles of the magnet. The wire should be fine enough to vibrate easily (copper wire of about 24 gauge works well). When 3 to 5 amperes of 60-cycle a.c. is passed through the wire, the number of nodes will depend upon the tension. Tension may be adjusted by adding or subtracting masses to one end.

2.32. MONOCHROMATIC LIGHT SOURCE

For many demonstrations it is important that the light be substantially monochromatic. Two sources are the sodium vapor lamp and the mercury vapor lamp.

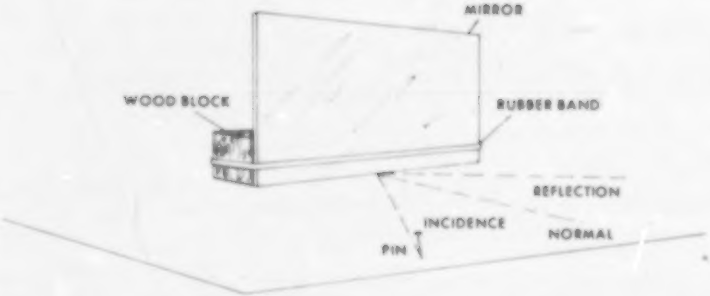
There are other methods of producing the yellow sodium light:

- A collar of blotting paper, paper towel or asbestos paper is made to fit the top of a bunsen burner, and held in place with a rubber band or loop of wire, with its top edge extended beyond the tube of the burner. The paper is wet with a sodium chloride solution, and the flame adjusted so that the air supply is sufficient to prevent incandescence of unburned carbon. For best results, the paper must be kept wet.

- A second method requires less attention and presents less danger of fouling the burner. A test tube containing a strong salt solution is plugged with a roll of blotting paper which extends into the solution and projects about an inch from the end of the test tube. The test tube is held in an inclined position with a clamp so that the paper, wet with the solution, extends into the flame of a bunsen burner. The flame itself must be adjusted to provide as little visible light as possible.

2.33. THE LAW OF REFLECTION

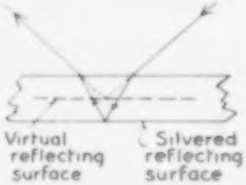
A small mirror is held in a vertical plane by fastening it with tape or rubber bands to a rectangular block of wood. The mirror stands on a sheet of paper, and a pin is stuck into the paper in front of it. A ruler is used to help locate a ray appearing to come from the image of the pin. After drawing incident and reflected rays and the normal, a protractor is used to verify the law of reflection.


MIRROR
WOOD BLOCK
RUBBER BAND
REFLECTION
INCIDENCE
NORMAL
PIN

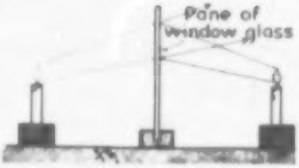
2.34. CHARACTERISTICS OF AN IMAGE IN A PLANE MIRROR

A small mirror is mounted as described in the preceding activity. A ruler is used to locate sight lines to reference points on the image of a simple but irregular figure previously drawn on the paper. The position of the virtual image is found by extending these sight lines to the point where they meet behind the mirror. Measurements then can be made of the sizes and distances of image and object, and the necessary comparisons made.

One source of difficulty with measurements of the distances from image and object to the reflecting surface is caused by the fact that the proper location of this surface is neither at the front nor at the back of the mirror. The accompanying diagram shows that refraction causes the mirror to appear to be thinner than it actually is, producing a sort of virtual reflecting surface in front of the actual silvered surface.


Virtual reflecting surface
Silvered reflecting surface

2.35. VIRTUAL NATURE OF PLANE MIRROR IMAGE



A very instructive and entertaining illusion may be assembled with two candles and a pane of window glass. The candles, as nearly identical as possible, are mounted on opposite sides of the vertical piece of glass. The rear candle is carefully placed at the position of the image of the front one formed by the glass. When only the front candle is burning, both appear to be lit, the virtual image of the flame appearing on the unlit candle. The glass plate must be large enough so the image can be seen from all parts of the classroom. The instructor can hold his finger in the "flame" of the rear candle without burning it, or expound a new method of "fireproofing" paper. When the rear candle or the glass is moved, the fact that only one candle is lit is immediately obvious. When the illusion is adjusted for best coincidence of candle and image, the object and image distances to the reflecting surface can be measured and of course will be equal. The fact that the image and object lie on a line perpendicular to the glass and that the image is virtual, erect and the same size as the object should be noted.

For an amusing variation, mount the unlit candle in a beaker, and pour water into it. Finally the flame appears to be under water.

2.36. "REVERSAL" OF MIRROR IMAGES

Part of the confusion on the question of whether a plane mirror reverses images arises from failure to distinguish between the usual laboratory situation (in which the miror plane and the plane containing the object and image are perpendicular) and the most common use of a mirror (the individual viewing his own image). In the latter case, the fact that a mirror does *not* produce the reversal expected when two persons (or a person and his image) face each other, causes the common and incorrect reference to the mirror's reversed image.

a. The letter "K," cut out of cardboard, and held so that the class can see both letter and image in a mirror shows that the left side of the letter produces the left side of the image. However, the same letter K, printed on a card and viewed in a mirror will appear reversed, but, of course, had to be physically reversed in order to make it face the mirror. The same sort of reasoning can be followed in using two students, one to represent the image of the other, and showing that reversal *would be necessary* for the image's right hand to appear on the proper side when facing the object.

b. Since the mirror's action in turning the image around to face the viewer without reversing it causes us not to see ourselves as others see us, it is interesting to bring about the reversal by using two mirrors. These are mounted as accurately as possible with their planes perpendicular, to form a right-angle corner, and with clean sharp (not beveled) edges in contact. When one looks at his image in this corner with the joint between the mirrors vertical, the two sides of the face are interchanged, and touching or winking one eye produces an effect on the opposite side—just as others would see it. To show that a corner reflection reverses the image rotate it 90° and the image will be reversed.

A corner reflector's property of reflecting light along a line parallel to its incident path is shown by the fact that the image does not move from the corner as the combination is rotated.

2.37. MULTIPLE REFLECTIONS

A burning candle is mounted in front of a plane mirror, and a plain sheet of window glass is put in front of the candle. The class can look through the glass and see the train of images formed in the mirror and in the glass by repeated reflection.

Using a second mirror instead of the clear glass makes many more images visible because of its greater reflecting efficiency. The viewer must look over the top of one of the mirrors.

2.38. MIRROR TRICKS AND SPECIAL APPLICATIONS

Many simple tricks and devices using mirrors are valuable because of their interesting features as well as their teaching values.

a. Arrangement of two mirrors on a sheet of paper to show their positions in a periscope is easy. A light ray can be traced on the paper showing this basic application of the law of reflection.

b. Two mirrors mounted with their reflecting surfaces perpendicular make a corner reflector, of which the major property is that any beam of light which shines into the corner in a plane perpendicular to the mirrors reflects back along itself no matter what the incident angle. This can also be set up on a sheet of paper and the rays traced to show why it has this property.

c. If the two mirrors are mounted vertically with edges touching, the angle between them can be varied, and multiple reflections of an object placed between them can be seen. Interested students who may be bored with the simplicity of the geometry of reflection can be challenged to derive a formula which gives the number of such reflections as a function of the angle between the mirrors.

d. If the reflecting surfaces of two mirrors make an angle of exactly 45° with each other, a light ray that is reflected first off one, then off the other, will emerge at right angles to its original path. If, this combination is fastened in a rigid framework, even though disturbed in position it will continue to reflect light in the desired direction. This arrangement can be set up and demonstrated with ruled rays. The geometrical proof is within the abilities of high school students.

e. A model sextant or range finder can be constructed. Both instruments are interesting mirror applications and illustrate the rotation of a reflected ray through twice the angular rotation of the mirror. Commercial kits are available.

f. When looking at one's own reflection in a plane mirror, the amount of the body seen in the image does not depend on the distance between the viewer and the mirror, although the amount of background seen does vary. This fact, easily proven with a small hand mirror is quite mystifying to pupils, and construction of ray diagrams to demonstrate the conditions is a worthwhile activity.

g. It can be proven that the minimum length of a mirror needed to reflect the head-to-foot image of a viewer is exactly half his height.

h. Studying the apparent reversal of mirror images is an interesting activity. "Mirror-writing," tracing around a complex figure while looking at the mirror image, and drawing a clock face that reads right when viewed in a mirror are examples.

2.39. DIFFUSED AND REGULAR REFLECTION

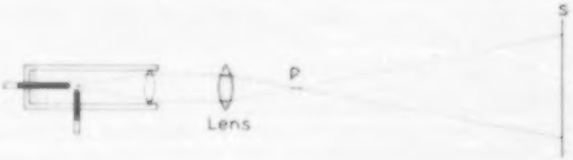
A spotlight is directed downward at an angle to the tabletop, its beam being reflected from a mirror resting on the table. The reflected spot of light on the wall or ceiling is noted, and the angle varied to show the equivalence of the angles of incidence and reflection. If desired, these can be measured. The mirror is then replaced by a sheet of white paper. The illumination of the ceiling and the visibility of objects in the room and of the reflecting surface is compared with the conditions produced by using the mirror.

2.40. REFRACTION BY GLASS PLATE

A rectangle of heavy plate glass is held so that a pencil is viewed through it. As the plate glass is rocked around a vertical axis, the image of the pencil, seen through the glass, is displaced to the side.

2.41. REFRACTION BY GASES

A convex lens is used in the beam from a projector or spotlight to produce a sharp focus at a point such as *P* and a large area of illumination on a screen. *P* now acts like a point source of light and objects placed between *P* and *S* cast sharp shadows. Any other convenient point source can be used. The room must be dark.



If the end of a piece of tubing connected to the gas line is placed in this part of the beam and the gas turned on, the shadow of the escaping gas can be seen because its index of refraction differs from that of the surrounding air.

The shadow of an operating bunsen burner shows the rising turbulence around and above the flame. A metal object, heated and placed in the beam produces convection currents which cast swirling shadows because of the changed refractive index of the heated air. This convection-refraction phenomenon produces the shimmering of objects seen through the air rising from a hot radiator or other heated surface.

2.42. MEASUREMENT OF INDEX OF REFRACTION

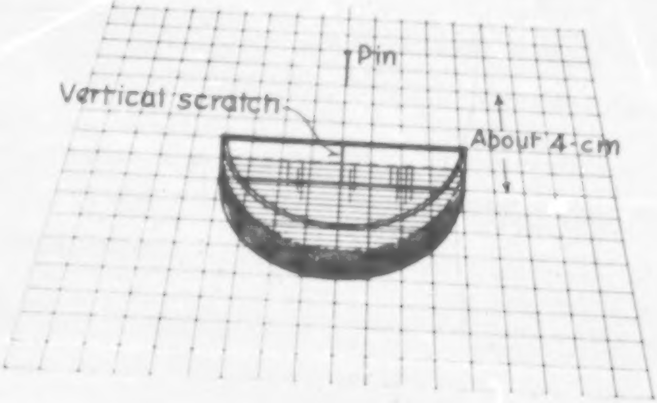
a. The index of refraction is computed from measurements of the angles of incidence and refraction. A shaft of light entering the surface of water at an oblique angle is made visible in the water by stirring in a little milk, soap solution or fluorescein or by making a sulfur suspension using hypo and sulfuric acid.

b. A crude measurement of refractive index can be made from the ratio of the real depth of a medium to its apparent depth. In the case of a liquid, when a ruler held in the liquid to measure its depth is viewed through the liquid surface, and a second ruler parallel to the first and outside the container is adjusted until its end appears at the same level as the first, the position of the liquid surface on the second ruler then measures the apparent depth. The same general procedure will work, using a glass plate on edge. A ruler is held in a vertical position against the far edge of the glass plate, and raised until its end appears to be level with the bottom corner of the glass. In either of these two procedures, the line of sight must be as nearly vertical as possible.

2.43. INDEX OF REFRACTION OF A LIQUID

The index of refraction of a liquid may be determined by using a semicircular, clear plastic box.

A vertical line is scratched at the center of the straight side of the box. Half fill the box with water and place it on a sheet of paper resting on a piece of soft cardboard. Press a pin through the paper and into the cardboard about 4 cm. from the box on the line perpendicular to the flat side at the center as shown in the diagram.



Sight through the curved side of the box and line up the scratch and the pin. Use a second pin to mark the line of sight. Move the first pin and determine the line of sight again. This process may be repeated several times. Mark the position of the box.

When the box is removed, the sight line and normals may be drawn and the index of refraction determined. If polar coordinate graph paper is used and the center line on the box placed at the origin, the angles may be read directly from the paper.

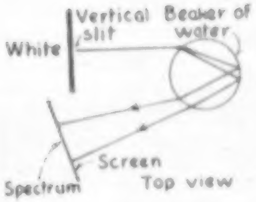
In sighting through the box, care should be taken to look through, not over, the liquid.

Other liquids, such as alcohol, may be used in place of water. Be sure to avoid the use of liquids which are toxic and/or which can dissolve the dish!

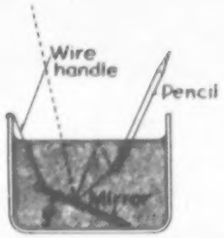
If a set of angles of incidence and refraction are obtained for a liquid, the ratios, Li/Lr and Sin Li/Sin Lr, may be plotted as a function of the angle of incidence and the concept of Snell's law developed.

2.44. RAINBOW

A beam of white light from a spotlight passes through a vertical slit and into a beaker of water. A spectrum shows on a screen placed on the same side of the beaker as the slit. The position of the beaker in the shaft of light is somewhat critical.



2.45. TOTAL INTERNAL REFLECTION

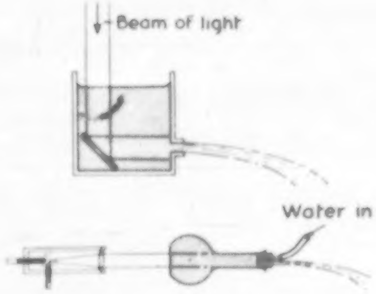


a. A mirror is placed in a jar of water and is held at an angle θ with the bottom. A clip of wire is fastened to the end of the mirror and a straight piece used for a handle so that the angle can be varied. The reflection of a pencil dipping into the water is viewed in the mirror. When angle θ is small, the whole length of the pencil can be seen, but as the angle is increased a point is reached at which only the portion of the pencil under the surface and its reflection in the surface are visible. If the pencil is now withdrawn, it disappears from view as soon as it leaves the water, showing that transmission through the surface at that angle is impossible.

b. If desired, an equivalent experiment can be performed somewhat less effectively without the mirror. The surface of the water in a beaker is viewed from below. A pencil is inserted, and the reflection of its submerged end can be seen in the underside of the water surface.

c. If an optical disk is available, total internal reflection can be demonstrated, using the semicircular glass attachment. A ray of light is made to enter the curved surface along a radius, and as its internal incident angle is increased by rotating the disk, the angle of the emergent light increases to 90°, and for greater incident angles complete reflection takes place in the glass.

d. A triangular prism is mounted on end on a printed page. The print can be read through the length of the prism, and reflections can be seen in the sidewalls. However, an object placed beside the prism on the page cannot be seen.



e. A beam of light can be made to follow a stream of water emerging from an orifice. A spotlight can be directed vertically downward into a can of water, its beam reflected off a mirror mounted at a 45° angle with the bottom of the can and out through a stream from an opening in the side of the can near the bottom

A second method is to have the spotlight directed through the flat bottom of a flask and through a water jet coming from a short piece of tubing in the stopper. In either case the light can be seen in the stream where it breaks into droplets, or can be shown on a white paddle of wood inserted anywhere in the water jet.

f. A demonstrator with which a light beam can be made to follow a curved plastic rod is listed in science supply catalogs.

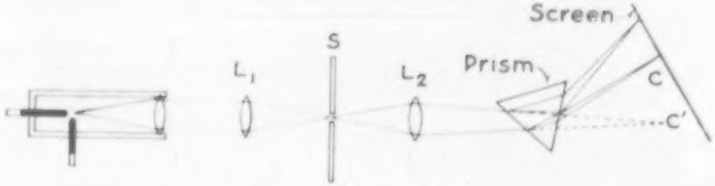
g. A metal ball such as that used in the ball and ring extension demonstration is coated with soot from a candle flame. When it is immersed in water, the soot retains a film of air so that it is not wet by the water. The resulting appearance of the ball shows a small black spot where the light reflects at angles less than the critical angle. The rest of the ball looks silvery, light being totally reflected at the water-air surface.

The leaves of some plants produce the same shiny appearance when in water, and for the same reason.

2.46. DISPERSION AND THE PROJECTION OF A CONTINUOUS SPECTRUM

a. Prism method. The purity of a projected spectrum depends on using a narrow slit and on focusing it sharply on the screen. In the diagram, L_1 is a converging lens used to direct as much light from the projector as possible on slit S and L_2 forms an image of S on the screen at the position C^1 before the prism is interposed. If the distance between prism and screen is not great, C^1 may be at the edge of the screen to be used to receive the spectrum. If dimensions do not permit this, a plane mirror or one face of the prism may be used as the position of the prism to reflect light to C and permit preliminary adjustment of L_2 to form a sharp image of S.

A slide projector makes a convenient substitute for the optical system of this demonstration. The slit is cut in an opaque slide, or it may be cut in a piece of cardboard or metal which will fit the slide holder. The only other equipment then needed is the prism and screen.



Instead of the illuminated slit, a straight-filament lamp may be used, masking out all but about a half inch of the filament.

If lens L_2 is large enough to allow some light to pass around the prism, the slit image at C' will be formed while the spectrum is produced at C. This emphasizes the bending of the light by the prism as well as the dispersion.

After calling attention to the geometry of the arrangement and to the order of the colors, the spectrum may be recombined to form white by focusing it with either a converging lens or a concave mirror.

b. Diffraction grating replica method. Commercially available diffraction grating replicas designed to be used with a slide projector can produce a large spectrum on a classroom screen.

c. Cuvettes. Hollowed 2 x 2-inch slide-like containers that are placed on the slide carrier of the projector can be used to demonstrate absorption spectra when they are filled with various liquids.

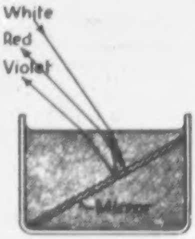
2.47. DEPENDENCE OF INDEX OF REFRACTION ON WAVELENGTH

The arrangement described in 2.46 may be used to show the greater refractive index of glass for blue light than for red. A double filter is made by holding a blue and a red filter together, edge to edge, with transparent tape. This is placed between L_1 and S, so that one end of the slit is illuminated with blue light, and the other half with red. The image of the bicolored slit is first displayed at *C'*, then the prism is moved into position, producing a spectrum which is split longitudinally, with a band of blue at one end of its halves and red at the opposite end. The presence of other colors depends on the density and purity of the filters used.

Removal of the filter displays the conventional continuous spectrum.

2.48. DISPERSION WITH A WATER PRISM

Light can be dispersed by the wedge-shaped volume of water between an inclined mirror and the surface. The ceiling of the classroom is a convenient screen for this spectrum.



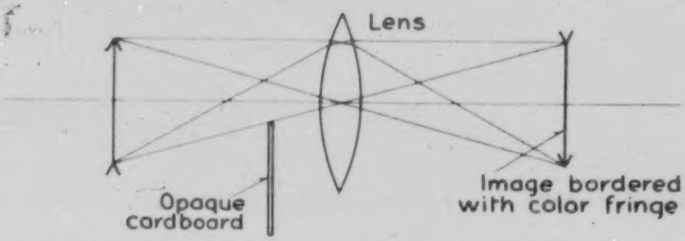
Students may be able to predict differences in the spectrum pattern that would be produced by using larger or smaller beakers to increase or decrease the size of the wedge of water.

It might prove profitable to discuss possible effects produced by heating or cooling the water. If a measurable difference occurs, students could prepare a temperature scale based on the changes in the spectrum pattern.

2.49. DISPERSION.

a. Dispersion in the eye. The optical system of the eye refracts light and is subject to dispersion effects. Students can experience this rather simply. Attention is directed to a sharp vertical boundary between light and dark, for example, a window frame. Each individual holds a card, or even his finger near his eye (with its edge parallel to the light boundary and gradually moves it into the field of vision, until it begins to distort the edge being viewed. At this point a band of color bounds the edge of the light area. If his card has moved from dark to light, the fringe of color will be red, and if moved from light to dark, blue.

The reason for this effect can be demonstrated using standard laboratory equipment. Use an uncorrected lens to cast a very bright clear image of a white light. As an opaque card is moved across the lens, a color border, red on one edge, blue on the other, appears around the image. Since only half the lens is used, it not only brings light to a focus, but also acts as a prism.



b. Dispersion by a lens. A large simple lens is used to cast the shadow image of a piece of wire screening which is brilliantly illuminated by the beam of a projector or spotlight behind it. The individual wires in the image are seen to be fringed with color—red on one side and blue on the other. When an achromatic lens is used, these colors cannot be seen.

The same general effect can be observed by producing the image of an operating straight tungsten filament. This lens effect is called chromatic aberration.

2.50. CONVEX LENS — DESCRIPTION OF IMAGE

Qualitative investigations of the images produced by a lens are easily adapted for either demonstration or individual pupil experiment.

Determination of the focal length is best done by forming the image of a distant object. Despite its greater distance, use of the sun as the object is not desirable because of the dazzling brilliance of its image, and the distracting smoldering of the screen.

A candle flame or any of the commercial illuminated objects can be used for formation of the images to be studied.

The effect of object distance on image nature and size can be demonstrated by holding a large convex lens so that it magnifies print for the class. The distance is gradually increased with a resulting increase in size of the virtual image, until inversion takes place as the focal point is passed. Continued increase of object distance results in decreasing the size of the real inverted image. Side-to-side motion of the viewer's head can show, by parallax, the position of the virtual image behind the object, and of the real image, in front of the lens.

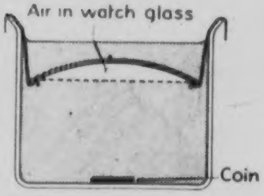
CAUTION:	Bright objects should never be focused on the eye retina with a lens.

2.51. INVERSION OF IMAGE IN THE EYE

A pin and a card with a pinhole in it can be used to show that the real image on the retina is inverted. The pin is held erect with its head about an inch from the eye. The card is held about an inch beyond the pin, with the pinhole in line with the eye and the head of the pin. The silhouette of the pin seen against the light coming from the pinhole appears to be inverted. The pin is actually so close to the eye that the lens cannot invert its image, and its shadow falls erect on the retina. The mental mechanism which reinverts the usual image to make it appear erect, inverts this erect shadow to make it seem inverted.

2.52. AIR LENS

A convex lens does not always converge light, as can be shown by using a convex air lens in water. An inverted watchglass is held under the surface of water, trapping a plano-convex lens-shaped volume of air. The reduced and erect images of objects on the bottom of the vessel show this to be a diverging lens.



Comparisons of the effect produced by shallow and deep watchglasses should stimulate interesting student discussion. The relationship of density to refraction should also be discussed. Can students relate this experience to the production of achromatic lenses?

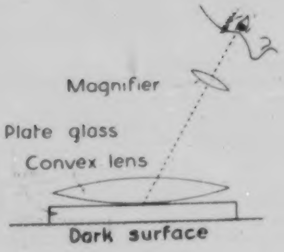
2.53. CONVEX LENS — SIZE AND DISTANCE OF IMAGE

A convenient object for a quantitative experiment involving object and image sizes can be made by cutting a rectangular hole 2 or 3 cm. on a side in a card, and mounting the card against an operating, frosted bulb, incandescent lamp. Stretching a piece of thread across this opening, held with cellophane tape, provides a sharp object to assist with focusing. A convex lens is used to cast the image on a screen, and object and image distances and sizes are measured, and their proportionality demonstrated.

The measured distance can be used to compute the focal length of the lens, and this figure compared with the focal length measured directly.

2.54. NEWTON'S RINGS

An interesting experiment with interference of light can be performed with a convex lens of large radius of curvature and a piece of plate glass. The glass rests on a dark surface and the lens on top of it. A tiny dark spot can be seen at the point of contact. This spot can be located most easily when the lens is pressed against the plate. Viewing this through a short focal length convex lens used as a magnifier shows it to be a series of concentric rings. When the lens is pressed against the glass plate, the rings enlarge with the local flattening of the interface.



The rings are caused by interference of the reflected light from the surfaces of the lens and the plate. The film of air between the two becomes thicker at greater distances from the point of contact, thus the paths of these two reflected rays differ in length. At each dark ring, they emerge out of phase.

2.55. INTERFERENCE OF LIGHT

Place two pieces of plate glass together, rest them on a dark background, and view the reflection of a sodium flame or other monochromatic light source. Irregularities in the surface of the usual plate glass produce an air space of varying thickness between the plates so that alternate light and dark bands of reinforcement and interference can be seen. Press on the top plate and the resulting distortion of the air space will make the bands move and change shape. Separate the plates at one edge by inserting a slip of very thin paper or plastic used for wrapping food. The resulting wedge of air produces fine parallel lines in the reflection. This simple apparatus can be used to measure the wavelength of the light. The wavelength is given by $\lambda = \frac{2dt}{l}$ where d is the distance between adjacent dark interference bands, t is the thickness of the plastic separating one edge of the plate, and l is the length of the plate.

The importance of this experiment lies in the fact that interference shows the wave nature of light. Point out also that the difference in the light paths for two adjacent bright bands is the wavelength of the light used; thus interference methods can be used to measure extremely short distances.

2.56. INTERFERENCE COLORS

a. The colors in a soap film are caused by interference of the light reflected from the two surfaces. Such a film can be formed across the mouth of a funnel. A cylindrical funnel will permit forming a plane film. The usual conical funnel can be used by fitting it with a short length of rubber tubing and a pinch clamp. This permits adjusting the pressure behind the film to locate it at the mouth of the funnel and also to give some control over its thickness. When the film is vertical, the water drains from top to bottom, producing a wedge-shaped layer, and causing horizontal color fringes. The colors are mostly easily seen when showing the reflection of a large white surface, such as an illuminated screen.

b. A wedge filter is available commercially. This is a layer of metal deposited on a glass plate and covered by a protecting plate. Both reflected and transmitted colors can be seen. It can be shown that at any point on the wedge, the reflected and transmitted colors are complementary.

c. A long playing phonograph record is held near the eye and the reflection of a straight-filament lamp viewed. The angle of incidence should be large and the grooves in the part of the record forming the reflection should be parallel to the filament of the lamp. Several orders of spectra are visible. "Diffraction jewelry," earrings, pins, etc. will also produce visible spectra.

2.57. INTERFERENCE PRODUCED BY TWO SLITS

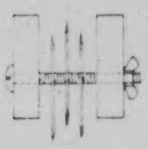
When light from a single line source falls on two narrow, closely spaced slits, an interference pattern is produced. For a line source, use a straight-filament "showcase" lamp. The slits are scratched with a razor blade or a sharp pin in an opaque coating on a piece of glass.

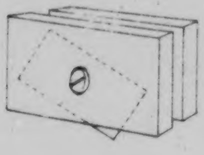
Old lantern slide plates or a cheap mirror may be used for the coated glass plates. If they are not available, a suitable surface may be prepared by painting one side of a microscope slide with a suspension of graphite in alcohol. Two double edged razor blades separated by a third blade are bolted between two pieces of plywood as shown in the diagram. This device may be used to make several pairs of slits.

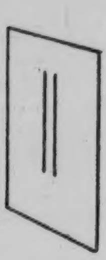
Look at a single filament lamp through the slits, holding the slits parallel to the filament and close to the eye. A pattern showing at least 3 clear white lines should be seen when looking at the filament.

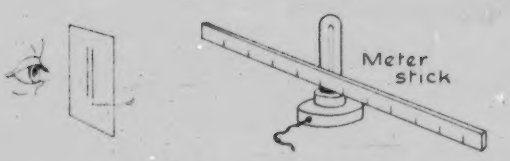
Cover part of the bulb with red cellophane and compare the pattern produced by the red light with that of the rest of the filament. Try it with blue cellophane and see how this pattern differs from the pattern using the red cellophane.

A slit film, developed at the Cornell Aeronautical Laboratory is available from several scientific supply houses for less than $2.00. The film has a number of single, double, and multiple slits of various widths and spacings. Detailed specifications for the slits and complete instructions for a number of experiments are usually included with the slit film.









2.58. USING A SLIDE PROJECTOR TO MEASURE THE WAVELENGTH OF LIGHT

An inexpensive replica grating and a slide projector may be used to demonstrate the measurement of the wavelength of light to a large group.

Make a single slit about 7 mm. to 8 mm. wide by masking a 2 x 2-inch slide with electrical tape. Place it in the slide holder of the projector in the usual manner. Tape the replica grating to the front lens of the projector. Be certain that the rulings on the grating and the slit are vertical.

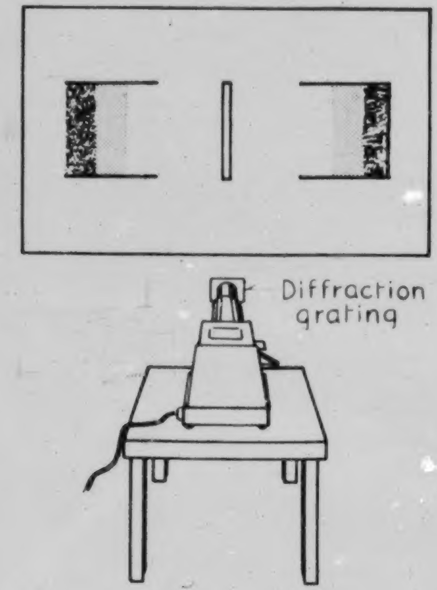
When a sharp image of the slit is focused on a screen, spectra will be visible on either side of it. If the room is very dark, more than one order of spectra may be visible.

Measure the distance from the central maximum to any color and the distance from the grating to the color on the screen.

Determine the wavelength of the color selected using the relationship

$$n\lambda = \frac{dx}{l}$$

Where n = 1 (1st order)
d = distance between the rulings on the grating
x = wavelength of light
l = distance from the grating to the screen



2.59. WAVELENGTH OF LIGHT USING A SPECTRAL SOURCE AND A DIFFRACTION GRATING

With a single spectral source set up near the center of a darkened laboratory, each student in a large class can measure the wavelengths of the spectral lines.

The students sight through a diffraction grating which has been fastened to a meter stick as shown in the diagram. Various devices which attach to meter sticks can be obtained from scientific supply houses and used for holding the grating and the sight. The center of the grating and the front sight are aligned with the source. The slide on the second meter stick is moved until it is coincident with the first order "spectral line to be measured." The wavelength can be calculated using the relationship:

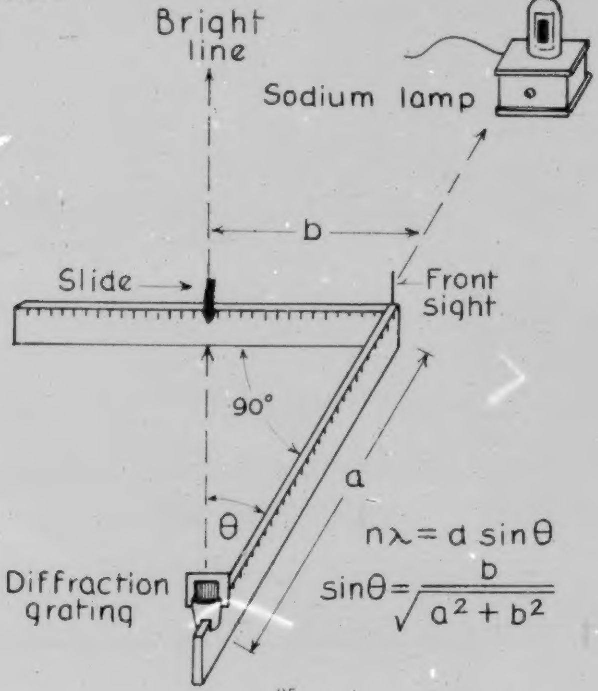
$$n\lambda = d \sin \theta.$$

Where n = 1 (1st order)
d = distance between the rulings on the grating
λ = wavelength of light

A variety of lamps containing such gases as hydrogen, water vapor, argon, neon, and other gases may be substituted for the sodium lamp shown in the diagram.

Accuracy may be improved by observing the first order spectra on both sides and determining the average value of b.

The obvious disadvantages of using a single spectral source are somewhat offset by the advantages of the low cost and simplicity of the apparatus.


Bright line
Sodium lamp
b
Slide
Front sight
90°
a
θ
Diffraction grating
$n\lambda = a \sin\theta$
$\sin\theta = \frac{b}{\sqrt{a^2 + b^2}}$

2.60. SINGLE-SLIT INTERFERENCE

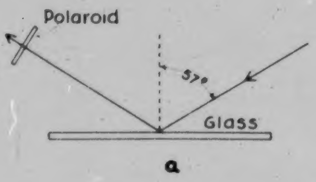
Individual students can easily observe effects which emphasize the wave nature of light. A straight-filament lamp is exposed on the demonstration bench. Each student looks at it through the slit formed between two fingers held close together, parallel to the filament and close to the eye. An interference pattern can also be seen by looking at the lamp through a single thickness of a cloth handkerchief, or through the eyelashes when the eyes are partly closed, the lashes being parallel to the filament.

2.61. POLARIZATION OF LIGHT

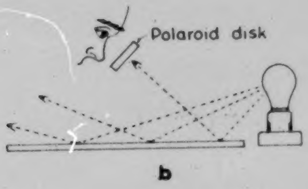
Polaroid disks or sheet can be used to polarize the light beam from a spotlight or a slide projector. The two pieces of polaroid are overlapped in the beam and it is seen that they are transparent in one position, and opaque when one is rotated through 90°. Either disk or sheet can be rotated to produce the effect. When both are rotated together no change occurs. This demonstration can be used to make clear the transverse nature of the wave motion.

2.62. POLARIZATION BY REFLECTION

a. Place a glass plate (not a mirror) on a tabletop and shine a beam from a spotlight on it at an angle of incidence of about 57°. Allow the reflected spot of light to fall on a screen. Hold a polaroid disk in the reflected beam and show by rotating the polaroid that the light is polarized. Change the angle of incidence to show that partial polarization occurs at other angles. Polaroid sun glasses use this principle to reduce reflected glare.

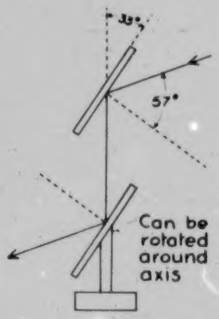


b. Mount an incandescent lamp over a plate of glass so that its reflection in the glass can be seen at a variety of angles. View the reflection through a Polaroid disk so as to produce cancellation at the best angle. Now as the line of sight is changed, it can be seen that complete polarization occurs at just one angle—partial polarization, at greater and smaller angles.



c. Show by the technique of *a* that light reflected from the surface of water in a beaker or even from the shiny tabletop is polarized. Note that the optimum angle will not be the same as for glass.

d. Polarization can be demonstrated without the use of Polaroid by reflecting from two glass plates. Mount a glass plate tilted at an angle of 33° from the vertical and shine a beam of light into the plate so that it is reflected vertically downward. Mount a second plate, at the same angle as the first and directly under it, on a stand so that it can be rotated around a vertical axis. When the second plate is rotated through 90° the beam reflected from it disappears and reappears as turning is continued, regaining full brightness at 180°.



d

2.63. POLARIZATION BY DOUBLE REFLECTION

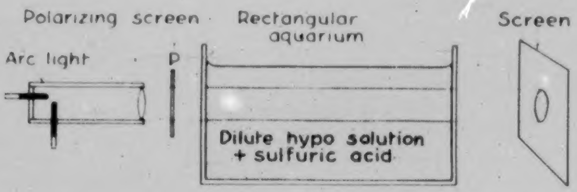
A clear crystal of calcite shows the property of double refraction. When print is viewed through it, each of the two resulting images is polarized, and the planes of polarization are perpendicular. When such a double image is seen through a Polaroid, first one, then the other disappears as the Polaroid is rotated.

2.64. POLARIZATION BY SCATTERING

One of the methods of studying the atmosphere of the earth and other planets has been by measuring the characteristics of polarized light which has been scattered by particles in the atmosphere.

Light from a part of the sky whose direction is at right angles to a line joining the observer and the sun is found to be partially polarized, when viewed through Polaroid.

A demonstration that illustrates this fact makes use of a suspension in water to produce the scattering. It also shows why the sky is blue and how sunset colors are created. A rectangular aquarium is filled with a dilute solution of hypo in water. A spotlight is arranged to shine through the water and onto a screen, inclined so that the class can see both the path of the beam in the water and the spot of light on the screen. After a few drops of sulfuric acid are stirred into the hypo solution, a sulfur suspension begins to form. The light beam in the water takes on a definitely blue hue, and the spot on the screen passes through various shades of yellow and orange to a deep red color. The spot, of course, represents the setting sun, its color becoming more red as the light must pass through greater distances in the earth's atmosphere, and as more and more blue is scattered by smoke and dust particles in the air.



The scattered beam, when viewed through Polaroid, is found to be polarized. This can be shown to a class by inserting a polarizing screen at point *P*. As the screen is rotated, the light passing through the suspension becomes successively brighter and fainter. If the Polaroid is held at a position which eliminates the light emerging horizontally, a mirror held over the tank will reveal that the beam is bright in the vertical direction.

2.65. ULTRAVIOLET SOURCES

Ultraviolet light can be detected with special films, fluorescing dyes and minerals. Examples are:

a. A 2-watt argon-filled glow lamp provides a weak source of ultraviolet light. While a single lamp is satisfactory for individual use in complete darkness, lamps must be arranged in banks of 10 or more to provide a sufficiently powerful source for demonstrations.

b. A special incandescent lamp produces enough ultraviolet for most purposes. For best results it should be mounted in a reflector. Its chief disadvantage is the high operating temperature which makes it inadvisable to use it for more than a few minutes at a time.

c. A carbon arc with an ultraviolet filter attachment provides a powerful, but rather inflexible source.

d. The germicidal or sterilamp can be used, taking precautions against their somewhat dangerous radiations.

e. A "black light" fluorescent lamp can be fitted with a supplementary filter to absorb its visible output.

f. Sunlamps of various types make rich ultraviolet sources.

CAUTION: Ultraviolet light may have a harmful effect on the retina of the eye.

2.66. THE BRIGHT-LINE SPECTRUM

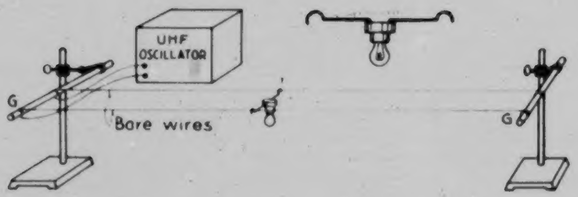
Individual students can see a bright line emission spectrum by viewing a capillary gas-discharge tube through a prism or grating held to the eye, or by using a piece of LP phonograph record as a reflector. The most successful gas is probably helium, producing brilliant lines separated far enough apart in its spectrum to be easily resolved. This can be seen from all points in a classroom when the source is operating on the lecture desk so that the prisms or gratings can be passed from student to student. If prisms are used, some preliminary instruction is necessary, covering the proper angle at which the prism must be held and the angle of viewing.

For comparison purposes, an operating straight-filament lamp to show a continuous spectrum and a slit in front of a sodium flame for monochromatic light should be displayed at the same time.

2.67. RADIO WAVES

a. The wave nature of broadcast radio and television signals can be emphasized by use of the known velocity and frequency of a broadcast wave to calculate its wavelength. For example, a radio station broadcasting on 880 kilocycles per second produces a wavelength of $\frac{3 \times 10^8}{8.8 \times 10^5} = 341$ meters. Some radio dials are calibrated in terms of wavelength as well as frequency.

It is desirable for a class to see the reality of radio waves and their wavelength, and to appreciate the features of such waves that are characteristic of wave motion generally. The Lecher wire technique can be used with an ultra-high-frequency oscillator as a spectacular and valuable demonstration. The Lecher wire apparatus is essentially a two-wire transmission line in which standing waves can be produced and detected. The similarity to the standing waves produced in a string or in an air column is obvious. The technique is described in most radio books, and in working detail in the *Radio Amateur's Handbook*.



Two bare wires, of unimportant diameter, and perhaps 10 feet long, are stretched between insulating supports. In the diagram the supports shown are pieces of glass tubing *G* held by ringstand clamps. The wires should be parallel, about 2 inches apart, and stretched tightly. At one end of the line, each wire is connected to an output terminal of the oscillator. Standing waves in the line are detected, so that the class can see, by a flashlight lamp suspended from the line. The lamp socket, which is as light as possible, has two short pieces of heavy wire soldered to it. These are bent so as to straddle the Lecher wires. The UHF oscillator may be any simple radio transmitter with a frequency of 150 mc. or higher. Several are described in the *Radio Amateur's Handbook* and in other radio texts.

To operate, turn on the oscillator and slide the lamp along the wires until it glows. This position must be a point of maximum potential in the wires. If the lamp is moved from this location, it goes out, but, if it is moved along further, it will light at another point, the next potential antinode. The measured distance between these maximums is half the wavelength. The frequency of the oscillator can be checked by use of the measured wavelength, and the known velocity of electromagnetic radiation. Compare this experiment with the production of nodes and antinodes in strings and air columns. Attention can also be drawn to the use of short antennas to receive UHF television signals and larger antennas for the VHF stations.

A student who has a hobby interest in amateur radio will be able to set up and operate the equipment.

2.68. LASER BEAMS AND OPTICS DEMONSTRATIONS

Commercially available compact gas lasers producing milliwatt beams of visible red light are extremely effective for demonstrating the laser function and beam convergence and divergence using concave and convex lenses. These laser systems can be used to demonstrate reflection, refraction, and polarization.

AREA THREE

ELECTRICITY

3.01. GENERAL SUGGESTIONS

CAUTION: All students should be made aware of the potential shock hazards present in electrical circuits. The dangerous feature of a shock is the current flow through the body which may cause severe pain, burns, or even death.

In general, students should not handle line voltages in tabletop circuits, and the power supplied should be isolated from the line. All line-voltage equipment should be properly grounded and it is strongly recommended that extension cords not be used unless they are of three wire construction and are capable of maintaining a proper ground connection.

First Aid

All accidents, however slight, should be reported to the school nurse, and all accident information forms should be carefully filled out.

Immediate first aid for severe shock should include the removal or inactivation of the current source and the immediate administration of artificial respiration.

a. Clip leads. In putting on electrical demonstrations, it is quite important that circuit connections be made quickly and accurately. The circuit that has been permanently laid out on a panel avoids this difficulty, but for many purposes changes in wiring must be made during a demonstration, and it is often desirable to wire a circuit with the class looking on. For this purpose, make about a dozen clip leads, each about a foot long, using flexible test lead wire and an alligator clip at each end.

b. Switches for the laboratory. The pushbutton is an ideal switch for the laboratory. Students should be required to include such a switch in every circuit, connected directly to the source. It reduces accidents to equipment, and does not permit the experimenter to walk away from his experiment leaving it turned on. Mount the pushbuttons on squares of $\frac{3}{4}$-inch wood, making connections with

Fahnestock clips. The type of pushbutton in which the metal button itself completes the circuit is not satisfactory for current larger than about 1 ampere.

c. *Resistors.* The values of fixed resistors to be used in experimental investigation of circuits must depend on available meters and voltage sources. Resistors of all values are available commercially and homemade resistors are also practical. Nichrome or chromel resistance wire, heavy enough (No. 22, for example) to form a self-supporting coil can be attached to a base and provided with contact clips to give resistance values up to about 3 ohms. For larger values the wire should be wound on a spool. Mount each resistor which is to be used repeatedly on an individual base and make connection to it with Fahnestock clips.

d. *Variable voltage sources.* Commercial power supplies can be purchased which incorporate desirable features such as voltage regulation, built-in meter circuit breakers, and in some cases line isolation.

e. *Meters.* Unmounted panel type meters are much less expensive than those in elaborate cases, are available in a wide variety of scale ranges, are rugged and accurate enough for student use and are easily mounted. The mount can be made of plastic, masonite, plywood or, if one of the binding posts is insulated, aluminum. Do not use sheet iron for the mount unless there is some indication on the meter that it was calibrated for mounting in a steel panel, in which case iron or steel should be used.

The 0-1 milliampere movement is especially useful. It is sensitive enough for use as a galvanometer, and can be readily converted to serve as a voltmeter of any desired range.

f. *Static electricity.* Experimenting with static electricity is most successful in cool dry weather, so that planning of the physics course should bring up this topic some time between late November and early March.

The topic of electrostatics presents many opportunities for spectacular and interest creating demonstrations. Paradoxically, this is one of its major pitfalls, since the explanations of many of the most interesting experiments may involve rather obscure or advanced scientific principles, or principles which are better taught in other ways or in other parts of the course. If explanations are incompletely understood, the lesson takes on the atmosphere of a magic show, and entertainment rather than learning becomes the prime objective of the class. In general, an experiment should not be given unless (1) it demonstrates some principle which either is fundamental to concepts to be developed later, has some "daily life" application, or satisfies some other accepted objective of the course, (2) it can be explained understandably at the level of the class being taught, and (3) its entertaining and spectacular features can be used directly to focus attention on its values for the teaching-learning process.

Some pieces of equipment, particularly the glass rod, silk threads supporting electroscope balls and the like, will work best if heated just before use. Place them over a hot radiator before class, or place them in a box containing an operating incandescent lamp for a short while before use.

Positive charges are easily obtained using strips of lucite or similar plastic materials instead of glass. Some caution is in order when using plastics because excessive rubbing will raise the temperature of the plastic to a point where the material will be charged negatively on some trials and positively on others.

3.02. ELECTROSCOPES

a. The pith ball electroscope has the advantage of being very light and responsive and the disadvantage of being rather small for a class to observe. The pith balls should be hung from a horizontal support, at a distance from any vertical support rod greater than the length of their threads. In addition to demonstrating the attraction and repulsion of like and unlike charges, a demonstrator with a steady hand can, by slowly moving a charged rod through an arc just outside the circle through which the pith balls can swing, carry them into an inverted position. After making the point that the electrostatic attraction is greater than the weight of the balls, slowly move the rod higher. The dependence of electrostatic attraction on distance is made obvious by the slackening of the threads and the fall of the pith balls.

b. Electroscopes of the same general operating characteristics as the pith balls, but having the advantage of greater visibility, can be made of ping-pong balls or corks coated with conducting paint or light foil or of inflated rubber balloons. An unconventional arrangement is made by inflating the balloons with hydrogen and holding them down at the end of 2- or 3-foot threads.

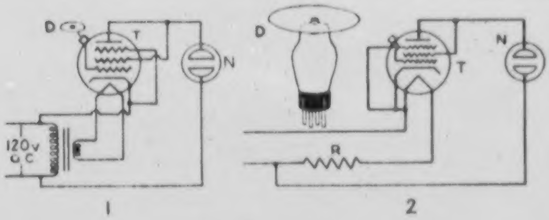
c. If a meter stick or other long thin piece of seasoned shellacked wood is supported at its center of gravity so that it can rotate freely in a horizontal plane, it can be used as an electroscope. The support may be a bent wire cradle hanging from a piece of thread, a rotating platform (available commercially) for mounting on a needle support, or the stick may be drilled at its center, fitted with a glass bearing and rested on a sharpened nail. A charged rod will attract one end of such a stick and make it rotate. If one end of the stick is wrapped with metal foil and charged, it will be repelled by a like charge and attracted by an unlike charge or by the demonstrator's finger.

d. A gold, or aluminum, leaf-type electroscope is extremely sensitive but is affected by air currents and must be kept in a glass container for protection. Because of these limitations this type of electroscope is not well suited—for lecture demonstrations and may be easily damaged in the laboratory by the application of large static charges. To improve visibility, the glass container may be wrapped with a single sheet of facial tissue, onion skin, or tracing paper and illuminated from behind by a point source so that shadows of the leaves appear on the paper. Another technique is to use a small low-voltage, high-intensity lamp in front of the electroscope and project the shadows of the leaves on a large screen several feet away. Special leaf electroscopes are made with flat sides to facilitate projection.

e. Commercial Braun electroscopes are recommended because they are large enough to be seen in class demonstrations without the necessity of projection and are satisfactorily sensitive and extremely rugged. They are more expensive than the leaf-type but are more versatile and will usually last longer.

f. This electroscope will respond to the motion of a charged rod at a distance of 10 feet or more, and will indicate the positive charge on the fur with which an ebonite rod has been rubbed.

A vacuum tube electroscope is extremely sensitive. The tube *T* is almost any voltage amplifier pentode with a grid cap (6C6, 6J7, 78, 6K7 etc.). The heater may be operated from a filament transformer as shown at (1), or directly from the line through a high wattage series resistor *R* as shown in (2). For the tubes named, a 40-watt incandescent lamp can be used as the resistor, but should be concealed from the class so that its light does not detract from the demonstration. *N* is a 2-watt neon lamp. In operation, one sector of the neon lamp glows. As a negatively charged object is brought near the grid cap of the tube, the neon lamp glows less brightly and finally goes out. A positively charged object will make the glow brighter as it approaches, but when withdrawn, the lamp is extinguished because of the electrons acquired by the grid when it was made positive.



1 2

The sensitivity is increased by mounting a 4-inch disk of copper *D* directly on the grid cap by means of a connector soldered to its center.

3.03. ATTRACTION AND REPULSION

a. The laws of attraction between unlike charges and repulsion between like charges can be shown by using the pith ball, ping-pong ball or balloon electroscopes previously described.

b. Dip a charged ebonite rod into cork filings. The rod will come away covered with the cork particles, but as they assume the same charge they will be repelled and fly off violently. The result is a shower of cork dust darting away from the rod in all directions. A charged electrophorus disk produces the same result.

c. A charged rod or comb brought near a gentle stream of water from the faucet will attract the stream, making it follow a most unnaturally bent path.

d. A piece of paper held against the wall or blackboard and struck sharply with the fur will be charged enough to stick to the vertical surface. If partly peeled off and released it will snap back into position.

e. An inflated balloon, rubbed with fur or wool will stick to the wall or ceiling of the classroom.

f. Suspend a charged rod horizontally using wire stirrups, easily made for this purpose or available commercially. Attraction of unlike charges and repulsion between like charges may be easily demonstrated using this apparatus.

3.04. THE ELECTROPHORUS

An electrophorus may be purchased or easily constructed. It consists of a flat plate of insulating material and a metal disk with an insulating handle. The base plate may be a layer of sealing wax melted in a pie pan or a discarded vinylite phonograph record. Rub the plate with fur or wool to charge it well. Set the disk on it and ground the disk with the finger. Now, when the disk is removed, it will have a charge opposite to that originally placed on the plate. A quarter-inch spark can be drawn from the disk to the demonstrator's finger. The disk can be charged repeatedly without further charging the base.

Use an electroscope to show the nature of the charge on both disk and plate and explain the process of charging by induction. The charged electrophorus disk can be used as a reliable source of charges for other experiments.

3.05. THE ELECTROSTATIC MACHINE

The most common electrostatic generators are induction machines of the Wimshurst or Van de Graaff types. After the electrophorus has been demonstrated and explained, exhibit and use an induction machine, explaining it as a continuous action electrophorus. These machines are reliable in almost all weather conditions as a source of charge at very high voltage. The plates or belts should be kept clean. If there is no response to turning the crank of the Wimshurst machine, charge some of the metal sectors on one of the glass disks by using a charged rod.

The spark discharge between the knobs will punch tiny holes in a card, and will go around the edge of a piece of window glass. The potential necessary to produce a discharge between knobs is about 30,000 volts per cm. of spark.

When using the Wimshurst machine, the distinction between potential and charge can be approached by noting the change in the nature of the spark with and without use of the machine's Leyden jars.

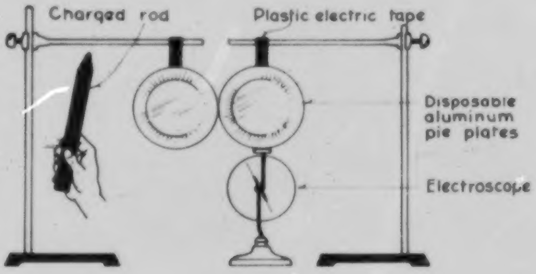
3.06. CONSERVATION OF CHARGE

Press a piece of plastic electrical tape to the knob of an uncharged electroscope. Grasp one end of the tape and pull it off the knob quickly. The tape and the electroscope will receive equal amounts of opposite charge by the process. Bring the tape near another electroscope with a known charge to establish that the tape is charged negatively. Bring charged rubber and glass rods near the original electroscope to establish that the electroscope is positively charged. Touching the charged tape to the knob of the original electroscope will neutralize the electroscope and confirm the conservation of charge.

3.07. ELECTROSTATIC CONDUCTION AND INDUCTION

Disposable aluminum pie plates are valuable for many electrostatic demonstrations because of their small mass, large surface, and rounded edges. These features are ideal for transference, detection, and retention of static charges.

Isolate two pie plates by suspending them with plastic electric tape from ring stands as shown in the diagram.



With the electroscope touching the edge of one of the plates, conduction of charge may be demonstrated by bringing a charged rod near the most distant pie plate and observing the electroscope leaves when the plates are making contact with each other. To demonstrate induced charges, set up the apparatus as shown in the diagram and then move the ring stands to separate the plates. Remove the charged rod being careful not to touch the pie plate. With the electroscope, show that the pie plates are oppositely charged. Separation of the plates prevents electron redistribution after the rod is removed. Repeat this, substituting charged rubber rods, glass rods, or various types of plastics, and have the class predict the polarity of each of the pie plates after they are separated.

3.08. COULOMB'S LAW

Qualitative and quantitative demonstrations of Coulomb's law are possible using a coated pith ball which is suspended by two silk or nylon threads from an overhead support and then charged. Holding a similar charged ball at the end of an insulated rod at various distances from the suspended ball will result in a deflection which may be varied by changing the distance between two balls. A graph can be plotted to show the inverse relationship between the distance and deflection. Unless the air is quite dry, the small charges leak off the charged balls ratner rapidly and small air currents make it difficult to determine changes in deflection. Also, careful electrostatic shielding is necessary to minimize static fields in the vicinity of the apparatus that are created by the clothing of the experimenter and other external extraneous sources.

3.09. DISCHARGE FROM POINTS

a. A needle attached by wire or a spring clip to one knob of a Wimshurst machine can be used to show that a charge is lost so rapidly from a point that a large spark cannot be produced. With the needle attached to the positive knob, hold a candle flame in front of the point to show the actual motion of ions away from the point. Have a student hold his hand near the needle point to feel the air moving away from it.

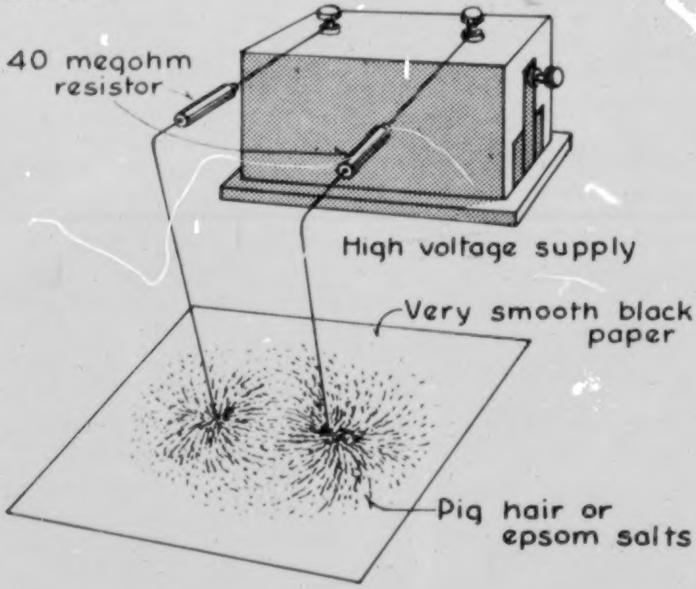
b. An electric whirl may be operated by connection to a static machine. This device is a fylfot made of wire with the ends sharpened, and pivoted on a needle point at the center of the cross. Discharge from the points causes a reaction, making the device spin.

c. A device to illustrate the functioning of a lightning rod is available commercially or may be easily constructed. Two metal plates are mounted parallel to each other horizontally and 4 or 5 inches apart. They must be insulated, and each connected to a terminal of a static machine. A metal post with a smooth knob on it is placed on the lower plate and its height adjusted so that a spark can jump to it from the upper plate. Now if a pointed metal post of the same height is added (the lightning rod) the sparking is prevented. If the apparatus is to be homemade, one may use a can for a house, and protect it with a lightning rod (a large sharp tack).

d. Discharge an electroscope by bringing a needle held in the hand near it.

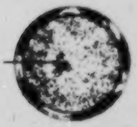
3.10. ELECTRIC FIELDS

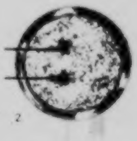
Electric field configurations may be demonstrated with an overhead projector, a high voltage source, and some dried pig hair, fine grass seed or needlelike epsom salt crystals. A battery operated induction coil is recommended but a neon-sign transformer may be used if limiting 40 megohm resistors are connected in series with the secondary wires. Observe normal precautions to insure that the high-voltage leads do not come into contact with the projector or the demonstrator.



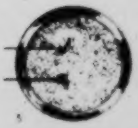
Sprinkle some dried pig hair, fine grass seed, or epsom salt crystals on a sheet of clear acetate placed on the projector stage. Adjust one or more electrodes to contact the surface of the acetate and then apply the voltage and tap the projector stage until the particles align themselves in response to the lines of force.

Figure 1 illustrates the typical pattern produced by a single electrode. Figure 2 shows the result when two electrodes of opposite polarity are close to each other. Figure 3 illustrates the pattern formed by two electrodes having the same polarity. Figure 4 shows the shielding effect in the center of a wire ring. Figure 5 illustrates the effects produced by an irregularly shaped electrode. The last two illustrations are produced by parallel electrodes having the same and the opposite polarities.

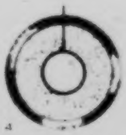




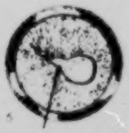
2



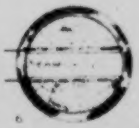
3



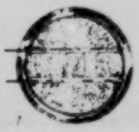
4



5



6



7

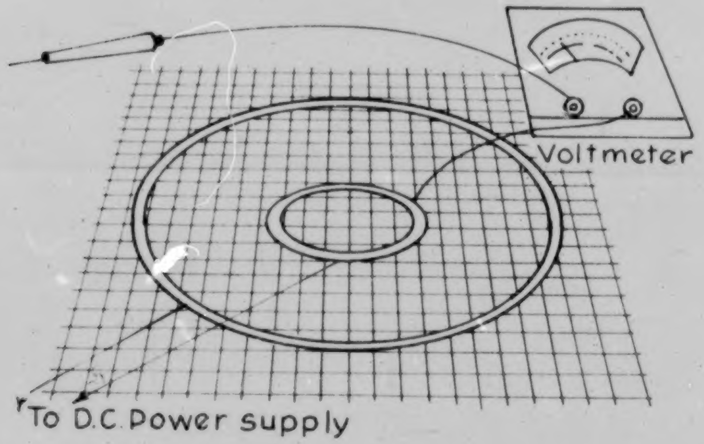
3.11. MAPPING ELECTRIC FIELDS

A weak electric field may be set up for investigation by connecting the output of a low-voltage (6 to 30 volts a.c. or d.c.) power supply to two metal electrodes that are spaced about 5 to 10 inches apart in a flat bottom, transparent dish which is filled with ordinary tap water to a depth of about $\frac{1}{2}$-inch. The electrodes may be short pieces of metal pipe, strips of copper or sheet metal, or even pieces of aluminum foil of various lengths and shapes. Place a sheet of graph paper under the dish.

Using a voltmeter that is appropriate to the a.c or the d.c. power supply, connect one lead of the meter to one of the electrodes and use the other voltmeter lead as a probe which is inserted into the water at each of the grid intersections in turn. The students may then record each voltmeter reading at the corresponding intersection of a similar piece of graph paper and then draw equipotential lines at 1 volt intervals and electric field lines to complete the mapping of the field.

Instead of measuring the voltage at each intersection, positions which give one or more pre-selected readings (10; 20; etc.) may be located. These equipotential points may be connected to form the equipotential line. Field lines may be drawn perpendicular to the equipotential lines.

For a lecture-demonstration in which the entire class can participate, use an overhead projector with a transparent grid, a glass or plastic dish of water, and a projection voltmeter on the stage as shown in the diagram. The probe position and voltmeter reading can be projected and will be visible to the entire class. The students can plot the data on a piece of graph paper while they remain at their seats.



If an a.c. power supply is used, an oscilloscope may be used as a detector instead of the voltmeter. Turn off the horizontal sweep of the oscilloscope and attach two probes to the vertical input. Place one probe in a fixed position in the dish. Whenever the second probe is at a point in the dish that is at the same potential as the point where the first probe is located, the vertical deflection will be a minimum.

3.12. POTENTIAL DROP IN A CIRCUIT

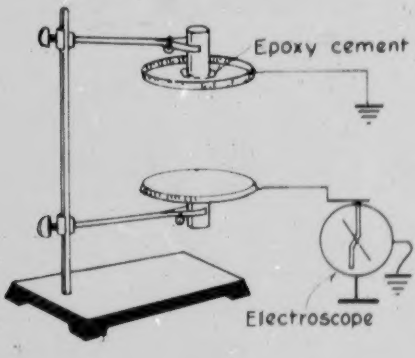
The student development of concepts that voltage is a measure of the potential *difference* between *two points*; that there is a potential drop in a conductor carrying a current, and that this drop is proportional to the resistance for a given current are fundamental to an understanding of electric circuits.

Stretch a 1-meter length of resistance wire along a meter stick and attach the ends to the terminals of a dry cell. Connect one terminal of a voltmeter to one end of the wire and make the other connection by means of a clip lead which can be slid along the wire. As the contact is moved from one end of the wire to the other, the concepts mentioned above become apparent.

A graph of the potential difference as a function of the distance between the voltmeter terminal is linear, and its slope is the potential gradient. Using the definition of the volt, show that the potential gradient in volts per meter is the same as the field strength in newtons per coulomb. The field is maintained in the wire by the source.

3.13. ELECTRIC POTENTIAL

To show that the electric potential increases as oppositely charged objects are separated, isolate two disposable aluminum pie plates and mount them on ring stands as shown in the diagram.



Because these plates are so light, cellophane tape or a drop of cement may be used to fasten each plate to its support. With the plates parallel and slightly separated, ground one and connect the other to the knob of an electroscope. Charge the ungrounded plate with a rubber rod or an electrostatic machine and have the class observe the angular deflection of the electroscope leaves as the ring stands are moved to separate the plates or to move them closer together. A graph may be drawn to show the inverse relationship between the voltage, as shown by the electroscope, and the distance between the charges.

Connect a neon lamp between the charged plates and a flash will be observed. The potential energy between the charged plates is transformed into light energy as the electrons flow in the direction of the electric field and work is done by the charges as they neutralize each other.

3.14. ELECTRIC CURRENT AND TRANSFER OF CHARGE

This effective demonstration introduces the concept of an electric current and shows the association between static and current electricity. A 2- or 3-foot length of dry cotton string is connected to the knob of an electroscope and stretched horizontally to an insulated support. The electroscope is not affected when a charged electrophorus disk or the knob of an operating electrostatic machine is touched to the end of the string. Now the fingers are moistened and run along the string. The resistance is lowered enough so that the electroscope leaves slowly diverge when the other end of the string is touched by a charged object.

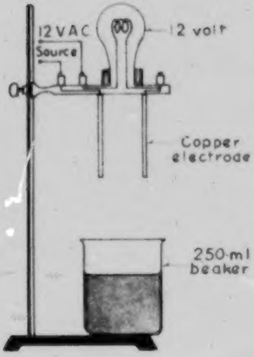
Charge the electroscope directly, and then discharge it by touching the other end of the moist string with the fingers. The electroscope discharges more quickly if the string is touched at a point close to the electroscope rather than at the opposite end, showing the dependence of resistance on length.

A troublesome feature of this demonstration is that the resistance of the string increases as it dries. If the string is first soaked in a weak salt or ammonium chloride solution and then dried, it will have the high resistance conducting characteristics of the moist string, but will remain constant in behavior.

The much greater conductivity of copper can be shown by replacing the string with a length of copper wire.

3.15. CONDUCTIVITY OF SOLUTIONS

The ability of solutions to conduct electric current can be shown with either teacher-made or commercial apparatus. The diagram on the next page shows one possible set up. The use of low voltage is suggested for safety reasons. A 12 volt d.c. power pack is a good power source. *Do not use an autotransformer to reduce the voltage because autotransformers do not isolate the circuit from the line.*



3.16. CONDUCTION IN GASES

The demonstration basic to developing an understanding of electrical conduction in gases requires a long glass tube with two sealed-in electrodes at its ends, a vacuum pump connection, a good motor-driven pump and an induction coil. The demonstration is most effective in a darkened room.

Evacuate the tube while the coil is supplying a high voltage to the electrodes. Watch the changing appearance of the discharge as the pressure is reduced. The bright pink glow that fills the tube occurs at a pressure of about 10 mm. of mercury and is similar to the type of discharge used in neon advertising signs.

As the pumping continues, a bluish glow covers the cathode, similar to the cathode glow seen in a neon glow lamp. The bright column begins to break into layers or striations. Bring a strong magnet near the tube and note that these layers are shifted in position.

The discharge is brighter if the coil is replaced by a high-voltage ("neon") transformer but in this case there is no indication of polarity in the tube.

3.17. DISCHARGES IN GASES

Discarded "neon signs" are often available as a donation. Secondhand transformers are inexpensive. Show the different colors obtainable with the various gases and colored glass tubing.

Scientific supply houses sell gas discharge tubes intended for spectrum analysis which can be operated from an inducation coil. Helium gas gives a brilliant pinkish white glow, argon a soft violet, and neon its typical red-orange.

CAUTION:	The transformers used with neon signs can be dangerous.

3.18. IONS IN FLAME

a. A bunsen burner or candle flame is brought near the knob of a charged electroscope. The electroscope is quickly discharged by the ions formed in the flame.

b. Show the presence of positive ions in the flame by holding it near one knob of a static machine. When the machine is operated, the flame will be repelled by the positive knob and attracted by the negative knob.

3.19. OHM'S LAW

In a metallic circuit of nearly constant temperature, the current is directly proportional to the potential difference (Ohm's Law). The resistance is the constant ratio between potential difference and current. These concepts may be illustrated with simple demonstrations.

Using a metallic resistor that has a resistance appropriate to the available source and meter ranges, measure the current for several values of potential difference. Show that there is a direct proportion.

Holding the voltage constant, use several known resistors, and measure the current to show that it is inversely proportional to the resistance.

This experiment can be used to illustrate graphical methods of reporting quantitative situations. With constant resistance a graph of current against difference of potential is linear and passes through the origin. In the second case, when the potential difference is held constant, the graph of current against the resistance is hyperbolic. A common technique in dealing graphically with such a relationship is to plot the reciprocal of current against the resistance, so that the result is linear. This permits interpolation and extrapolation by use of a straightedge.

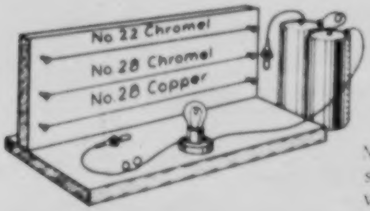
Repeat the experiment using a nonmetallic conductor such as a crystal diode or an electrolytic cell, and show that the relationship between current and voltage is not linear.

3.20. USE OF THE NEON LAMP AS A TESTER

The ordinary 2-watt neon lamp is an extremely useful demonstration device. It glows when the voltage between its plates reaches 75 volts and extinguishes when it drops to 60 volts. Its brightness is directly related to the applied e.m.f., making it useful as a rough indicator of the magnitude of an e.m.f. Since the glow takes place at the negative plate, a 2-watt neon lamp in a d.c. circuit can be used as a polarity indicator. On a.c. the plates glow alternately so rapidly that both appear to glow, giving a visual method for identifying a.c. Since it flashes 120 times a second on 60 cycles per second a.c., it also can be used as a low-power stroboscopic light source.

For individual use, a small tester with attached prods and built-in current limiting resistor is available commercially, at a very reasonable price.

3.21. LAWS OF RESISTANCE



A qualitative demonstration of the factors determining the resistance of a conductor is shown with a prepared panel. Half meter lengths of No. 22 and No. 28 chromel and No. 28 copper wire are stretched horizontally on a vertical board as shown. Connect two dry cells and a flashlight bulb in series with the piece of No. 28 chromel wire. Show the influence of length by sliding one of the contacts along the wire. Show the effect of diameter by comparing the brightness of the lamp when the No. 22 and No. 28 chromel are individually connected in series in the circuit. Similarly, compare the No. 28 copper with the No. 28 chromel to show the effect of the nature of the materials.

The demonstration may be made quantitative by substituting an ammeter for the lamp and simultaneously measuring the potential difference. However, this length of copper results in too small a resistance to be accurately measured by this method.

The same panel may be used to demonstrate the characteristics of series and parallel circuits, using just the chromel conductors.

3.22. THE LAWS OF RESISTANCE (QUANTITATIVE)

Quantitative measurements can be made of the effect of length, diameter, and material on the resistance of a conductor. Sets of coils are available commercially, or can be constructed. The coils should be wound on a piece of 1-inch dowel about 6-inches long, using small blocks to mount the coil assembly above a base, so that the coils clear the base. Make connection by means of Fahnestock clips. Secure the ends of each coil by passing them through holes drilled in the dowel, and shellac the coils.

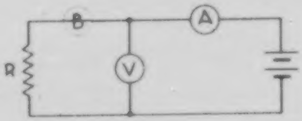
Suitable specifications for coils are (1) 10 meters of No. 30 copper, (2) 10 meters of No. 30 German silver (or some insulated wire other than copper), (3) 20 meters of No. 30 copper, and (4) 20 meters of No. 24 copper. Cement a typed label to the base, giving these specifications. Compare coils No. 1 and No. 2 to show the effect of material, compare coils No. 1 and No. 3 to show how length affects resistance, and compare coils No. 3 and No. 4 to show the part played by the diameter of the conductor.

Use a wire table in conjunction with this experiment, so that calculations of the coil resistance can be compared with their measured resistances.

Calculate the resistivity of each material and compare the results with those from tables in handbooks.

3.23. RESISTANCE BY VOLTMETER—AMMETER METHOD

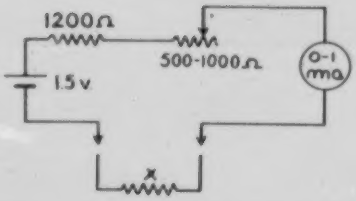
The circuit diagram illustrated is extremely accurate for measuring usual low value resistances. The unknown resistors used in the experiment could consist of resistance coils, and a collection of home appliances such as: irons, toasters, electric frying pans, electric hot plates, and such other appliances as may be readily available.



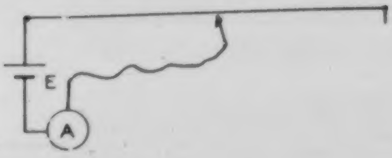
If the size of the resistor is an appreciable fraction of the voltmeter resistance, the ammeter should be moved to position *B* for greatest accuracy. Comparison of these two circuits is a valuable student exercise.

3.24. OHMMETER

The principle of the ohmmeter can be illustrated by the circuit shown. *X* is the resistance to be measured. Show the inverted and non-linear nature of the ohmmeter scale and the method of zeroing. Make approximate measurements of several resistances in the 200- to 3,000-ohm range.



3.25. OHM'S LAW AND THE RHEOSTAT



To show that current depends on resistance, or resistance on length, and to introduce the rheostat as a device for controlling current, support a 2- or 3-foot length of resistance wire and connect it in series with an ammeter and dry cell. Make one connection to the wire with a clip which can slide along the wire. Be careful not to exceed the full scale rating of the ammeter. If desired, a flashlight lamp can be substituted for the ammeter.

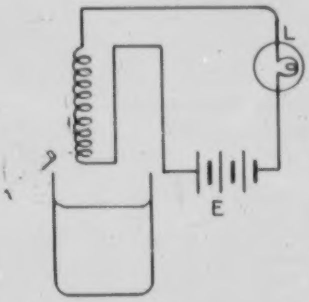
3.26. RESISTANCE OF THE HUMAN SKIN AND BODY

Measure the resistance from hand to hand by holding the two test leads of an ohmmeter on its highest resistance range. Show that when the skin is moist, the resistance decreases.

If an ohmmeter is not available, show a qualitative indication of the body as a conductor by connecting a dry cell in series with a galvanometer and two contacts which can be touched with the fingers. Mount the contacts so that they cannot possibly be brought into contact with each other.

3.27. EFFECT OF TEMPERATURE ON RESISTANCE

a. A coil of bare or enameled copper wire (about No. 26, for instance) wound on a tube of asbestos paper or on a piece of ceramic tubing such as is used as a feed-through insulator will exhibit a large change in resistance when heated. It is connected in series with an ammeter and a voltage source chosen so as to give almost full scale reading without undue temperature rise in the wire. Heat the coil with a bunsen flame and note the decrease in current.



b. A similar, and more dramatic method, is to use 3 or 4 feet of iron wire (No. 18 or No. 20) to wind a self-supporting coil, connecting it in series with a lamp *L* and the proper source *V* to make the lamp normally bright. A low-resistance lamp such as a 32-cp. auto stoplight lamp is best. Heat the coil with a bunsen flame and the lamp dims. Quench it in a beaker of water and the lamp immediately brightens. Finally, immerse the coil in a mixture of dry ice and alcohol to make the lamp even brighter than it was originally.

c. After a class has studied the laws of resistance, the students should be challenged to explain the following phenomena—shown without comment. A parallel combination of two 3.6-volt flashlight lamps is connected in series first with a 60-watt tungsten filament light, then with a 16-cp. carbon filament lamp, and operated from the 120-volt line. With the tungsten lamp in the circuit, the small lamps will flare brightly the instant the switch is closed because of the low resistance of tungsten when cold, then settle down to approximately normal brightness when the tungsten heats up. The opposite occurs when in series with the carbon filament because of carbon's negative temperature coefficient.

3.28. OHM'S LAW AND TEMPERATURE VARIATIONS

After the voltmeter-ammeter method of measuring resistance has been established, ask the class to measure the resistance of a flashlight lamp at various voltages up to and slightly over its rated voltage. Filament control rheostats from very old radios are about the right value to give control of the voltage. Have the students plot a graph of *I* against *V* and explain the curvature and the fact that it appears to violate the linear nature of Ohm's Law. Also plot *R* against *I*.

3.29. ELECTRICAL EQUIVALENT OF HEAT

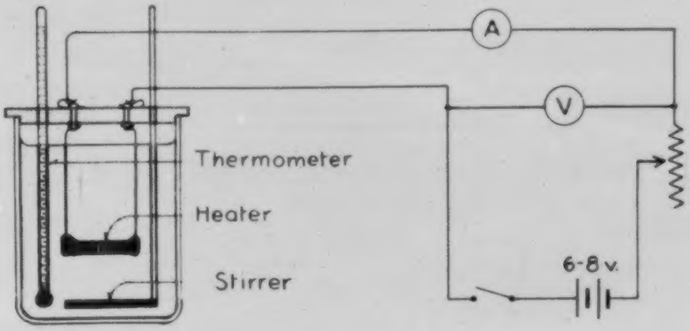
It is possible to measure the electrical equivalent of heat with ordinary apparatus.

A top for a homemade calorimeter may be cut out of wood, masonite or plastic. Holes are drilled through it for a thermometer and a stirrer, and two binding posts are provided to make electrical connection to a heater. The heater is an ordinary 5-ohm, 5-watt wire-wound ceramic resistor. It is hung in the center of the calorimeter by its own leads. The supply is about 6 volts and should be constant. If dry cells are used, at least two parallel banks should be connected to reduce polarization difficulties.

Heat Energy = Electrical Energy

$mc\Delta t = E.I.t.$
m = mass of water (Kg)
c = specific heat of water
Δt = change in temperature (C°)
E = potential in volts
I = current in amps
t = time in seconds

Arrange the apparatus as shown with the calorimeter containing about 100 gm. of water, or enough to cover the heater. Close the switch and start measuring the time. Stir the water and keep track of the temperature. If the voltage varies, either adjust it to the original value with the rheostat, or take repeated readings of voltage and current so that a mean value can be used in making calculations.



Using the suggested values, a 10-minute heating period will cause the water temperature to rise about 10° C. The experiment should be concluded before the temperature difference is great enough to introduce serious error. Compute the number of watt-seconds in a kilocalorie. The accepted value is $4.19 \times 10^3 \frac{\text{watt-seconds}}{\text{kilocalorie}}$ or

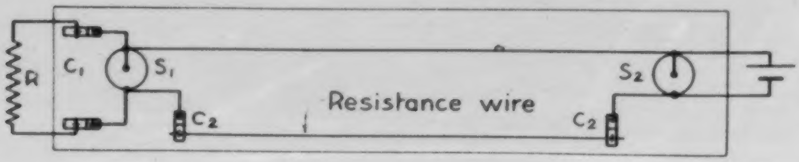
$4.19 \times 10^3 \frac{\text{joules}}{\text{kilocalorie}}$

Using the same apparatus and making the measurements, it is possible to change the goal of this experiment. Instead of confirming the value of V, use the experiment to help students understand the meaning of potential difference and the definition of the volt. Calculate the total energy supplied to the water in joules, and the total charge that passed through the heater. The number of joules per coulomb is, of course the voltage, which is confirmed by the reading of the voltmeter.

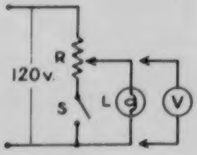
3.30. LINE DROP

a. The fact that there is a loss of potential in a line carrying a current can be shown without special equipment. An a.c. voltmeter is connected by means of a standard male plug to one outlet of a dual receptacle. Into the other outlet are plugged various appliances, and the resulting line voltage is compared with that occurring when no current is drawn.

b. The reason for drop in potential in a transmission line can be shown with this device. Attach two miniature sockets S, and 4 Fahnestock clips C, to a 2-foot strip of wood as shown. The connection between clips C_2 is made with a piece of resistance wire. R is a resistance of about 1 or 2 ohms. When R is not connected, the lamps at S_1 and S_2 are about the same brightness. When R is connected, S_1 dims, S_2 is unaffected. This resembles the dimming of lights in a house when an iron is plugged in. The resistance wire can be replaced with copper wire, in which case there is no discernible change in brightness when the resistor is connected. The potential drop in the resistance wire can be measured with a voltmeter, and an ammeter used to indicate the change in current when R is connected.



3.31. COMPARISON OF RHEOSTAT AND POTENTIOMETER



The use of a variable resistor as a rheostat should be compared with its action when connected as a potentiometer. In the circuit shown, *R* is about 500 ohms, rated at 50 watts, *S* is a single pole, single throw switch, and *L* is a 25-watt, 120-volt lamp. While these values can be changed considerably, *R* must be able to carry both the lamp current and its own current with *S* closed.

With the switch open, *R* is used as a rheostat, and the lamp can be dimmed only. When *S* is closed, *R* is a potential divider, and the voltage supplied to the lamp can be reduced to zero. In this case, we have a portion of the resistance in parallel with the lamp and the rest in series, resulting in much greater power use than when operated as a rheostat.

A voltmeter in parallel with the lamp aids in making the voltage control clear. This circuit can also be used with dry cells, a flashlight lamp, and rheostat of lower resistance, if desired.

3.32. THE SERIES CIRCUIT

The same equipment specified in 3.34 for the study of the parallel circuit will serve to show the characteristics of a series circuit.

- By moving the ammeter from one position in the circuit to another, show that the current is the same in all parts of the circuit.
- Switch the two resistors to show that the current is unaffected by which resistor "comes first."
- Use the voltmeter to measure the applied voltage and the potential drop in each resistor and show their relationship.
- Show that the potential drop in the resistor is that voltage necessary to cause the measured current in that value resistance. Compute the necessary p.d. from the known resistance and the measured current and compare with the voltmeter readings.
- Show that switches and fuses must be placed in series with the circuits they are to control.
- From current and source voltage, compute the total resistances and compare them with the sum of the individual resistances.

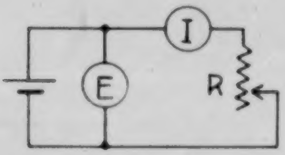
3.33. INTERNAL RESISTANCE

The potential drop within a cell delivering a current is caused by its internal resistance. This can be demonstrated by measuring its voltage under varying load conditions. R is a rheostat of about 10 ohms maximum resistance. As its resistance is decreased, the current increases and the voltmeter reading decreases. The decrease in voltage is the potential drop required to get the circuit current through the cell.

This setup can be used satisfactorily for a quantitative experiment. Measure the e.m.f. of the cell with R disconnected. This is (nearly) the open circuit e.m.f. Connect R and adjust it so that there is a significant difference in voltmeter reading. Then the internal resistance of the cell is

$$r = \frac{V_o - V}{I}$$

where V_o is the open circuit e.m.f. and V and I the voltage and current under load. Rewrite the formula, $V = V_o - Ir$. When V is plotted against I the slope will be the negative of the internal resistance and the intercept on the V axis will be the true terminal voltage.

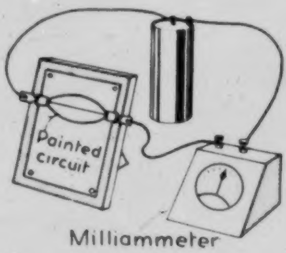


Make similar measurements for an old flashlight cell and a fresh flashlight cell.

Emphasize the fact that all voltage sources have internal resistance.

3.34. PARALLEL CIRCUITS

a. An interesting, but approximate, introduction to the parallel circuit can be shown by fastening a sheet of absorbent paper to a flat, inclined or vertical support, clipping connecting wire to the edges of the paper, and painting the circuit on the paper with conducting solution. Salt water colored with ink works well. Moisten the paper thoroughly around the clips before painting the



circuit. Work fast, because the resistance changes as the solvent evaporates. The concept that the resistance of a parallel circuit is decreased by adding a branch is very evident. A comparison can be made with the modern printed circuit.

b. Two resistors of different known values, an ammeter, a voltmeter and a source can be used to show the characteristics of a parallel circuit.

- Measure the current in each branch, and the total current, and show their relationship.
- Use the voltmeter to show that each branch receives the source voltage.
- Show that opening one branch does not interfere with the functioning of the other.
- Use the total current and the supply voltage to compute the combined resistance, and show that it is smaller than the lesser of the two branches.
- Derive the reciprocal resistance relationship, and show that the joint resistance computed this way agrees with that computed from meter readings.

3.35. MEASUREMENT OF ELECTRIC POWER

In addition to the usual voltmeter-ammeter method of measuring power, a kilowatt-hour meter can be used. Lighting companies are often willing to loan such a meter for school use. Connect a device of known wattage and count the number of rotations of the disk per minute. Then substitute the device whose power is unknown and repeat. There is a direct proportion between the speed of rotation of the disk and the power. Such an experiment can be done as a home exercise by making sure that all other appliances are disconnected and that the refrigerator or oil burner does not start during the test. Make the distinction between electric power, measured by the rate at which the disk turns, and electric energy, measured by the total number of rotations of the disk.

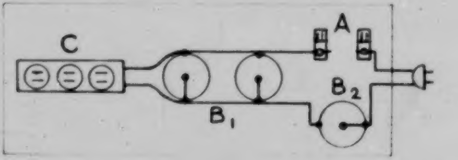
3.36. HEATING EFFECT OF A CURRENT

Several useful concepts of physics can be developed with a nichrome heating element replacement purchased in hardware departments or appliance repair centers. This comes as a tight coil which when pulled out straight is about 20 feet long. Stretch this wire along the side of the laboratory, make a return connection from the far end with copper wire and plug in directly on the 120-volt line. Paper riders show the temperature by smoldering, and the expansion of the wire causes it to sag sharply. Shimmering of objects viewed over the wire shows convection currents. The effect is more marked if a shorter length is used. Any 15-20-ohm length of chromel or nichrome wire will work in place of the heating elements.

After the circuit is opened, have students feel that the copper wire did not heat up and ask for an explanation.

3.37. FUSES

a. Fuses for experimentation may be cut from metal foil, the width determining the current-carrying capacity. The ends of such a fuse are conveniently held by paper clips.



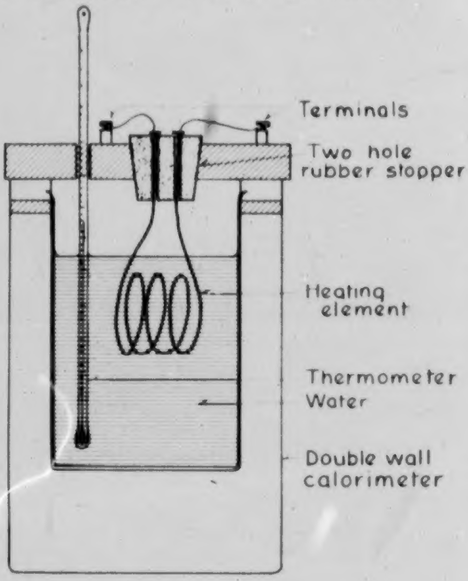
b. Prepare a fuse demonstrator as shown, with two Fahnestock clips *A*, three sockets *B*, and a multiple outlet *C*. A commercial fuse is inserted in the series-connected socket B_2, and either 2-amps. fuse wire or a strip of foil inserted between the clips. A lamp is screwed into one of the parallel-wired sockets and the device plugged in. A short circuit is contrived by inserting an insulated screwdriver into the empty socket. The fuse can be overloaded by plugging various heating devices into the outlets. If it is desired to blow out a commercial fuse of lower amperage rating than the line fuses, connect the clips with a piece of copper wire. Keep eyes and faces away when blowing the bare fuse wire as particles fly.

Show the danger of putting a penny in the fuse socket (a trick so well known that there need be no fear of teaching a dangerous practice). Connect clips *A* with a 6-inch piece of No. 28 chromel wire, representing in an exaggerated way the resistance of the house wiring. Drop a penny in socket B_2 and hold it down with a "burned out" fuse. Now when various appliances are plugged in, there is little difficulty in seeing why a fire may result. Remove the penny, use a good 5-amp. fuse and show that the fuse prevents the overheating by melting when overloaded.

3.38. EFFICIENCY OF AN ELECTRIC STOVE

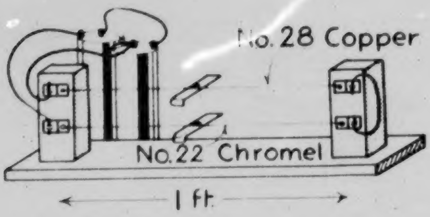
A measurement of the efficiency with which an electric stove transfers the heat converted from electric energy to the contents of a pot makes a desirable contact between the physics course and home problems. A measured quality of water is heated for a definite time on an electric hotplate, and from the mass of the water, the temperature rise, and the material and mass of the container, the heat absorbed is computed. A voltmeter, ammeter, and clock provide the measurements necessary to calculate the energy supplied to the hotplate. The input energy and the useful heat are stated in the same units by use of the equivalence 4.19×10^3 joules = 1 kilocalorie, before solving for the efficiency. The losses involved in the procedure, and the sources of error should be discussed.

It is interesting to compare the efficiency of the kitchen apparatus described above with an arrangement in which heat losses have been reduced.



Mount a small heating coil in the cup of a double wall calorimeter as shown in the diagram. Inexpensive coils which are ideal for this purpose are widely available in hardware and variety stores as one-cup coffee heaters. If the voltage is limited to 20 to 30 volts by using a variac, the experiment will be safe and the heat will be applied slowly. In this case, 100 grams of water in the calorimeter will become about 1°C. warmer each 60 seconds and efficiencies better than 90 percent are typical. Styrofoam, "hot drink" cups make acceptable calorimeters for individual student use.

3.39. HEATING IN SERIES AND PARALLEL CIRCUITS



The larger of two series resistors develops more heat than the other, and in a parallel circuit the smaller resistor of the two gets hotter. This can be easily illustrated as follows:

Stretch one-third meter lengths of No. 28 copper wire and No. 22 chromel wire between supports as shown.

Attach tabs of cardboard to the underside of each wire with candle wax. Complete the circuit as in the diagram. The tab indicates the hotter of the two wires by dropping off. Repeat with the two wires in parallel. If the chromel is not available, a similar length of nichrome wire from a heating element will work.

Power can be supplied from a variable low-voltage transformer. Paper labels identifying the wire are bent and hung on each wire. The heat generated in each is revealed by the smoldering of the label.

3.40. INCREASING THE VISIBILITY OF MAGNETISM DEMONSTRATIONS

a. A large magnetic needle, mounted on a low-friction bearing, and swinging in a horizontal plane, can be placed on the stage of an overhead projector for use as an indicator of magnetic effects. The reactions of the needle can be made more easily observable if paper tags bearing the symbols *N* and *S* are attached to its north and south poles.

b. The polarity of permanent magnets to be used in demonstrations should be made apparent. This is conveniently accomplished by painting the *N* pole of each magnet bright red, or by using red plastic tape. Avoid getting paint on the pole face itself.

When using magnets on the overhead projector, acetate tabs which extend beyond the end of the magnet can be printed *N* or *S*.

3.41. THE VECTOR NATURE OF A MAGNETIC FIELD

a. Although mapping the field of a magnet by sprinkling iron filings on a card over the magnet shows the shape of the field quickly and graphically, the procedure does not contribute as much to understanding the nature of the field as by plotting it with a small compass.

Place a bar magnet flat on the center of a sheet of paper and mark its outline and polarity on the paper. Then place a compass on the paper near one pole and make a pencil dot on the paper at each end of its needle. Move the compass away from the magnet until the end which was nearest the magnet is over the outer of the two dots, and make another dot at the far end of the needle. Continue in this way until the line of dots reaches either the edge of the paper or the other pole of the magnet. Connect the dots to show the line of force, and indicate its direction.

If the whole field is plotted carefully this way and the position of the magnet is not changed during the experiment, distortion due to the earth's field will show up.

b. The field strength at any point in the vicinity of two magnets is the vector sum of the two separate fields strengths. This concept can be developed by using a magnetic compass to determine the directions of the two fields separately at a given point, and of the resultant field at the same point when both magnets are in position. Using any convenient lengths for the resultant, complete the vector parallelogram and determine the ratio of the field strengths of the two magnets at that point.

3.42. MAGNETIC FIELD

A bar magnet is placed flat in a pan or dish of nonmagnetic material, and covered with about an inch of water. Magnetize a needle, thrust it through a wafer of cork and float it in the water with *N* end down. It will move in the field in the direction of the lines of force, always coming to rest at either the side of the container or the *S* pole. The greatest value of this experiment is that it emphasizes the fact that a line of force passing through a point indicates the direction of the resultant force on an *N* pole at that point.

3.43. THE MAGNETIC EFFECT OF A CURRENT

a. The field around a current-carrying conductor is most easily explored with a compass. Use a 3-foot length of fairly heavy insulated copper wire, a dry cell, and a pushbutton switch. Hold the wire over the compass and under it, parallel to the needle and at right angles to the needle. Reverse the current direction and repeat. Have students test Ampère's rule, and practice applying it.

b. Hold a portion of the wire vertically in any convenient way and sprinkle iron filings on a horizontal card through which the wire has been passed. Tap the card when the circuit is closed. This is a small effect and requires fairly heavy current to give good results.

c. Wind the wire around a pencil and withdraw the pencil to make a solenoid. Explore its field with the compass, noting polarity. Test and practice applying the hand rule for polarity of an electromagnet.

d. Show how the permeability of the core affects the magnetic strength. Hold the coil several inches from the compass, so that closing the switch barely causes motion of the needle, then insert a large nail in the coil and repeat.

e. Use a tangent galvanometer to show that the magnetic induction in the vicinity of a current-carrying conductor is directly proportional to the current. The apparatus is available from manufacturers, or can be constructed, and the experiment is described in several laboratory manuals.

3.44. STRENGTH OF AN ELECTROMAGNET

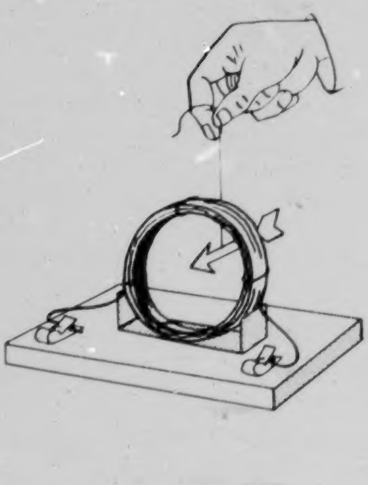
Students can plan and perform an experiment designed to show the quantitative factors which determine the strength of an electromagnet. This will generally take the form of showing that doubling the number of turns will double the number of paper clips or tacks which can be lifted, and doubling the current also doubles the strength. Since the result depends on several variables, this is a good way to illustrate the "controlled experiment" technique—holding all variables constant except the one being investigated.

Ask pupils to explain the comparative strengths of a magnet wound with 25 turns, and one wound with 50 turns, using twice the length of wire and the same source. The fact that there is little, if any, increase in strength is of course due to the decrease in current caused by the added resistance.

3.45. MAGNETIC FIELD OF A SOLENOID

A large coil and suspended magnet can be used to make the shape of the field of a solenoid clear. Wind a coil of about 50 turns of No. 24 or No. 26 copper wire on a cardboard form about eight inches in diameter. Hold the coil together by tying it with thread, remove it carefully from the form, and soak it well in shellac. Mount the coil vertically. Slip colored insulation or "spaghetti" over the leads so that they are easily visible to a class and bring them to clips or binding posts on the base. A large exploring compass is made from cardboard, in the form of a 4-inch arrow with several steel needles cemented to it. Magnetize the needles with the *N* end toward the arrow point, paint the arrow point red, and support the arrow from a length of thread.

In use, current is supplied by a single dry cell, and the arrow supported by the thread is moved around to make the shape of the field visible to the class. Since the direction of the winding is also apparent, the hand rules for direction of field and magnetic polarity can be taught using this device.



3.46. ELECTROMAGNET FROM FOCUS COIL OF A TELEVISION SET

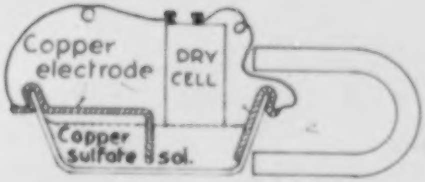
The focus coil from a discarded television set can be used as an effective electromagnet. Focus coils were placed around the neck of picture tubes of most sets manufactured in the 1940's and 1950's. The metal covering should be removed from the coil and the wire coils should be bound with a layer of electrical tape. An extra focus coil is a useful source of magnet wire.

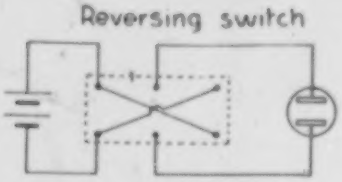
CAUTION: Television sets can be dangerous.

Before removing components, be certain that the high voltage tubes and capacitors have been grounded out and that the set is not connected to a supply cord. Television picture tubes must be handled with care and should be placed in well padded cardboard or wooden boxes for storage or disposal.

3.47. FORCE ON CURRENT-CARRYING LIQUID IN A MAGNETIC FIELD

A shallow glass pan can be placed on the stage of an overhead projector and copper electrodes and copper sulphate electrolyte added to produce a conductor. The apparatus is connected to a reversing switch and one or more dry cells. Set a horseshoe magnet next to the cell so that its field is vertical, or wind a coil around the dish and energize it with direct current. When current is passing through the solution, the liquid rotates. Reversing the connections to the dry cell reverses the direction of rotation. Sprinkle a bit of cork dust on the surface so that the motion of the liquid is easily seen.

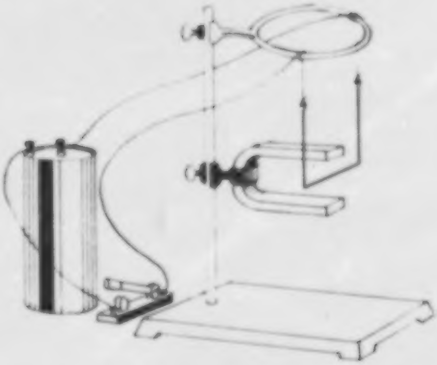




3.48. FORCE ON A STIFF WIRE IN A MAGNETIC FIELD

A stirrup or swing of stiff copper wire is suspended by hooks as shown in the diagram. It must make good electrical contacts at the hooks, yet swing freely between the poles of a strong magnet. Complete the circuit to a switch and dry cell.

If the polarity of the connection to the dry cell is made obvious, and the poles of the magnet are labeled, the appropriate hand rule is easily taught with this apparatus.



3.49. FORCE ON ALUMINUM FOIL IN A MAGNETIC FIELD

Lightweight strips of aluminum foil can carry currents up to 10 amps. without fusing and will respond dramatically in a magnetic field. These characteristics make these strips especially good for lecture-demonstrations and individual student laboratory investigations. Tinsel (metal-coated plastic) for decorating Christmas trees and aluminum strips obtained by unrolling a small paper capacitor work particularly well. Packaged aluminum foil of the type that is sold for wrapping foods is generally too thick and too stiff to respond to small forces.

a. Arrange a "*U*" magnet with the south pole up and electron current in the foil. The magnetic field which surrounds the foil will react with the upward field between the poles of the horseshoe magnet to snap the foil sharply.

b. Rest the "*U*" magnet on its poles. Pass a current through a length of aluminum foil, to make the foil arch dramatically. Increasing the current through the foil will increase the interacting magnetic forces proportionately and exaggerate the arch. Reverse either the magnet or the current to make the aluminum foil hug the table. If both the current and the magnet are reversed, the foil will again arch.

c. Mount the "*U*" magnet with the poles upward and apply current in the direction to make the foil flip over the pole.

d. Arrange a tunnel using several "*U*" magnets, alternating their polarity. Have the class predict the waveform that will be observed when the current or the magnets are reversed.

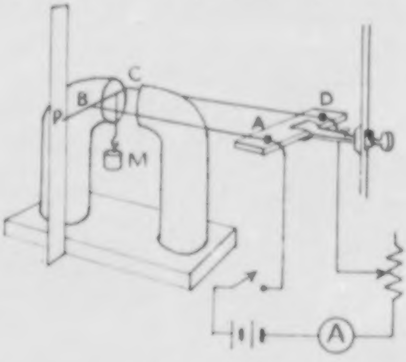
e. Clamp a long cylindrical alnico bar magnet in a vertical position and suspend a strip of aluminum foil so that it is no more than 1 or 2 cm. from the magnet. When direct current is supplied to the foil, it will twist about the bar magnet as the circular magnetic field about the foil and the characteristic field about the permanent magnet interact. Reverse the direction of the current and have the class explain why the aluminum foil first uncoils and then recoils in the opposite direction.

f. Make a long open ended loop with a strip of foil about 70 cm. long, connecting shorter lengths together with cellophane tape if necessary. The loop will hang limply as long as no current is applied to the ends of the loop. As soon as the current is applied, the loop diameter will expand as much as 7 cm. It will then slowly twist to the right or left to align its axis with the earth's magnetic field.

3.50. FLUX DENSITY OF A MAGNET

a. The flux density in a magnetic field may be defined in terms of the force on a moving charge. It is possible to determine this magnetic induction by directly measuring the force on a current carrying conductor in the field and using the relationship: $F = BIL$.

A strong magnet is needed for this experiment. Either a magnetron magnet, or a damping magnet from a kilowatt-hour meter will do. The current is passed through a long stirrup of nonmagnetic spring wire *ABCD* as shown in the diagram. The open ends of the wire are attached to binding posts on an insulating block which is rigidly held in a clamp. The polarity of the source is such that the resulting force on segment *BC* of the wire is upward. A hook for masses, *W*, is attached to the center of *BC* and a wire pointer *P* extends from one end of *BC* to a fixed scale.



The rest point of *P* is first noted when there is no current in the wire. Then a small weight of 1 gm. is hung at *W* and the current adjusted to return *P* to its starting point. This process is repeated for increasing weights. A graph of force (*W*) against the current is linear and its slope is used to determine the force per unit current. Dividing this by the length of *BC* gives the average flux density over *BC* at that particular position in the magnet gap.

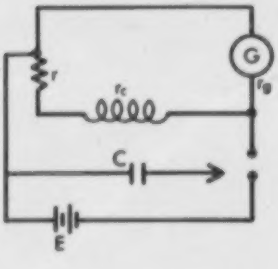
This procedure can be repeated at various positions between the magnet poles to see how *B* varies from one side of the air gap to the other.

The sensitivity of the apparatus can be increased by increasing the length of legs *AB* and *CD* and by using wire of smaller diameter. The best ammeter available should be used.

b. The snatch coil method of measuring flux density can also be used although it presents some experimental complexities. If a small coil attached to a ballistic galvanometer is suddenly moved from the region where the magnetic induction is to be measured to a region where the field is negligible, the charge which passes through the galvanometer and causes it to deflect is proportional to the induction. The relationship is: $B = \frac{Rq}{NA}$ where *B* is the induction, *R* the combined resistance of galvanometer and coil, *q* the charge, *N* the number of turns of the coil, and *A* the area enclosed by the coil.

The galvanometer need not be one specially built for ballistic use. Any moving coil galvanometer of known resistance can be used, although, because of the speed of the deflection, it takes some practice to read the maximum "kick" on the usual laboratory instrument. The snatch coil may be 40 or 50 turns of wire, held together by using the last turn to wrap the others. In order to calibrate the galvanometer, a large capacitor of known capacitance is charged to a known voltage and then discharged through the meter. The sensitivity of the meter is determined by knowing the charge delivered by the capacitor and the resulting meter deflection.

Since the snatch coil damps the galvanometer it must also be connected when the meter is calibrated. However, since the coil resistance is low, it shunts the meter too much when the capacitor is being discharged through it. Therefore, a resistor *r*, comparable to the meter resistance is placed in series with the coil.



Connect the circuit as shown in the diagram. When the capacitor is discharged the portion, *q*, of the original charge *Q* which passes through the meter is: $q = \frac{r + r_c}{r + r_c + r_g} \cdot Q$

where r is the added resistor, r_c is the coil resistance (probably negligible), r_g the galvanometer resistance, and q the charge of the capacitor. If q is now divided by the meter deflection, we have a measure of the sensitivity of the meter when used ballistically with r and the coil across its terminals.

The coil, in series with r and the meter, is now placed between the poles of the magnet being measured and suddenly removed. The resulting meter deflection is used with the previously measured sensitivity to give the charge q which is caused to flow. The radius of the coil is measured to determine its area and the magnetic flux density calculated from the equation stated above: $B = \frac{Rq}{NA}$.

NOTE: R is the sum of the resistances of the galvanometer, resistor and coil.

c. Low cost current balances for measuring the magnetic field at the center of a solenoid may be obtained from laboratory supply houses.

3.51. FORCE ON IONIZED GAS IN A MAGNETIC FIELD

The ionized mercury vapor in a clear fluorescent lamp will glow with a characteristic blue color which makes it visible in a classroom with normal lighting when the lamp is operating. In the strong field of an alnico magnet the beam is visibly deflected in a direction which is perpendicular to both the beam and the field.

For dramatic effects, operate the clear fluorescent lamp (GE type F15T8) with direct current. Because the conventional inductor-type ballast is unsuitable for d.c., use an ordinary 100-watt incandescent lamp as the series limiting resistor. If a variable d.c. power supply is not available, the apparatus may be operated from an a.c. outlet using a variable transformer and bridge rectifier.

Closing the switch momentarily allows the lamp filaments to heat up and ionizes the mercury gas in the tube. Once the arc is struck, the ionized mercury conducts sufficient current to maintain a closed circuit. In the electric field, the heavy positively-charged mercury ions migrate towards the negative terminal of the tube and the lighter electrons drift in the opposite direction.

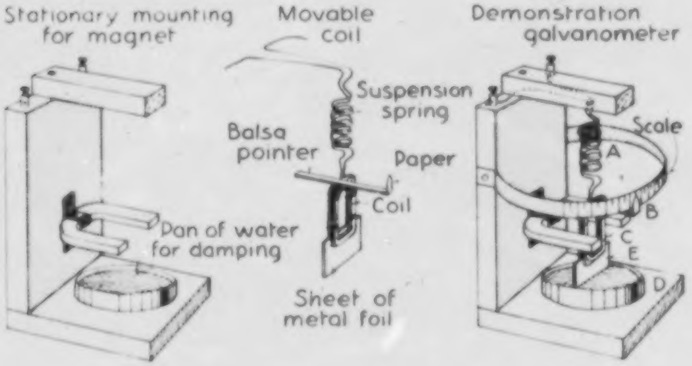
Placing a strong magnet near the side of the tube deflects the electron beam at right angles to the magnetic field. Because the mercury ions are moving in the *opposite direction*, their positive charge causes them to be deflected in the *same direction* as the electrons. The magnitude of the ion deflection, however, is different than the magnitude of the electron deflection in the same field. This difference results in a separation of the positive and negative charge carried along the width of the fluorescent tube. The potential difference between these charged areas can be detected by taping a pair of electrodes to the outside of the glass tube and connecting them to an electrometer. This voltage is known as the Hall Voltage.

CAUTION: Do not use voltages higher than those recommended.

3.52. PERMANENT MAGNETS

Physics students very often have preconceived notions about magnetic properties, including attraction and repulsion. Many experiments which demonstrate the properties of permanent magnets are described in detail in basic texts and laboratory manuals. Teachers should attempt to insure that students obtain accurate and concise knowledge of this subject. Activities concerned with magnets are essentially qualitative and should be designed to emphasize the identification of magnetic materials, the law of attraction and repulsion, observation and understanding of induced magnetism, and conceptualization of "lines of force" phenomena.

3.53. DEMONSTRATION GALVANOMETER


Stationary mounting for magnet
Movable coil
Demonstration galvanometer
Suspension spring
Balsa pointer
Paper
Coil
Pan of water for damping
Sheet of metal foil
Scale
A
B
C
E
D

A large demonstration galvanometer can be made from easily obtainable materials. *C* is a coil of 50 turns of No. 28 copper wire. Its width is such that it turns easily between the poles of the magnet. The ends of the coil are wound together around a pencil to make the suspension spring *A*. The coil is bound with thread and a slim stick of balsa is bound to the top of it as a pointer. It extends as far behind the coil as in front so that it is balanced, and has an upturned point of red paper. Damping, which is necessary, is provided by water in dish *D*, and a sheet of metal foil *E* attached to the coil and dipping in the water. Of course, the sensitivity of this galvanometer is not very great, and it should be demonstrated with a dry cell and series resistor.

Conversion of the galvanometer to an ammeter can be shown by use of a shunt of No. 30 wire, and to a voltmeter by the addition of a series multiplier.

3.54. ALNICO MAGNETS

The alloy, alnico, is capable of great magnetic strength, and is not readily demagnetized. Alnico magnets are made in many different shapes and can be used for most permanent magnet demonstrations. They have two limitations, which should be noted.

- Alnico magnets do not serve well to show the shape of magnetic fields by the method of sprinkling iron filings on a card placed over the magnet. Their great strength sweeps the field clear in the magnet's vicinity, causing the filings to cluster at the poles.
- Small magnetic compasses are easily reversed in the field of an alnico magnet.

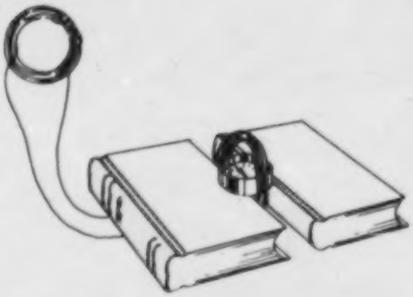
Several special forms of alnico magnets are useful.

a. Cylindrical magnets can be used to show magnetic forces. If two such cylinders are placed on a smooth surface with like poles together, they will fly apart when released. If one rests on the table, and the other is rolled toward it so as to repel it, the moving one will transfer its momentum to the one initially at rest without coming into contact with the other.

b. Horseshoe-shaped alnico magnets with a keeper and hook are available commercially. Such a magnet can support many times its own weight.

c. Alnico magnetron magnets are available on the surplus market. In addition to being very useful in demonstrating production of induced voltages, the great strength of these magnets makes possible many spectacular demonstrations. A handful of paper clips tossed in the general direction of such a magnet will be unerringly caught. A 3-dimensional array of paper clips or small nails can be attached to the poles to show the lines of force.

3.55. INDUCED VOLTAGES



If coils and galvanometers are not at hand for student investigation of induced currents, it is possible for students to make acceptable substitutes for both. Wind about 50 turns of wire (No. 24 or No. 26) around two fingers and finish the coil by wrapping the free end of the wire around the turns several times to hold the coil together. Then, without cutting the wire, leave about 2 feet of wire free and wind another similar coil, finishing it the same way. Save about 2 feet of wire at the end for the return connection to the first coil, and make this connection. This now gives two identical small coils connected in series. Use one, with a small compass, for a tangent galvanometer. Support it between 2 books or blocks of wood, with its plane in an *N-S* direction, and the compass within it, holding the connecting wires down by passing them under one of the books.

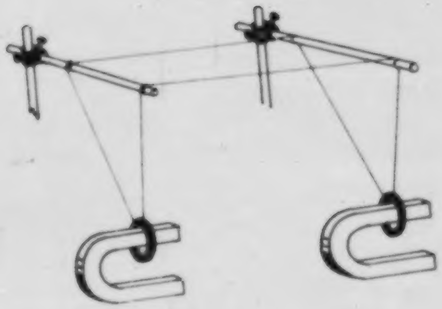
Thrust the other coil over one pole of a strong permanent magnet and note the deflection. (NOTE: Move the coil, not the magnet, otherwise the motion of the magnet may affect the compass.) Emphasize the need for relative *motion* to induce an e.m.f. Note the effect of speed of motion, of direction of motion, and of magnet polarity. Place 2 bar magnets with *N* poles together and note the effect of magnetic strength.

Study the direction of wind of both coils and by applying Ampère's rule to the direction of compass deflection, determine the direction of current when the coil is thrust over an *N* pole. From this, determine the polarity of the coil in which the e.m.f. is being induced. State and demonstrate Lenz's Law, and emphasize that it is a consequence of conservation of energy.

3.56. INDUCTION AND MOTION OF CURRENT-CARRYING CONDUCTOR IN FIELD

Wind a coil of about 50 turns of No. 26 enameled copper wire around three fingers of the hand, and wrap it with the free end of the wire to hold the coil in place. Without cutting the wire, take 3 or 4 feet of extra wire off the spool and wind a similar coil, leaving another length for the return connection. With the coils in series, hang each by its own leads just high enough above the table top to swing freely over the pole of a strong horseshoe magnet. The points of suspension must be the same height so that the coils acting as pendulums have the same period.

When one coil is set swinging the other quickly responds. When the circuit is open the motion of one coil has no effect on the other. In addition to illustrating electrical relationships, this experiment can be used to help establish the concept of resonance. It is instructive to reverse the polarity of one of the magnets and discuss the result. Insert a galvanometer in the circuit between the coils to show the current causing the effect.



3.57. GENERATION USING THE EARTH'S MAGNETIC FIELD

A voltage large enough to cause a visible deflection of a lecture galvanometer or projection meter can be generated by swinging a long wire through the earth's magnetic field. When a wire about 3 meters long moves (as one would swing a long jump rope) with its axis perpendicular to the earth's magnetic field, about 0.5 millivolts will be generated. If a sensitive electrometer or a cathode ray oscilloscope is used as a detector, the deflection will be more apparent to the class.

An interesting effect may be demonstrated if 2 conductor lamp cords are used for the wire and a high impedance device, such as vacuum tube voltmeter, is used as a detector. If one terminal of the meter is connected to one end of the conductors and the other terminal of the meter is connected to the other end of the second conductor, the meter will be deflected even though the circuit seems to be incomplete. This is because the circuit is completed by the capacitance between the two conductors.

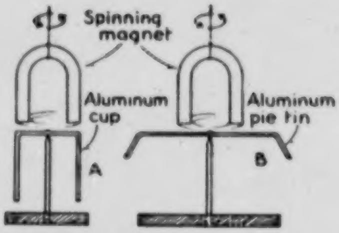
3.58. LENZ'S LAW

Lenz's Law can be demonstrated with an undamped galvanometer. When it is rocked (cautiously), the needle swings back and forth freely and will oscillate for several seconds before coming to rest. Connect a wire directly across the terminals and the action is damped by the field of the current resulting when the coil cuts across the field of the permanent magnet in the instrument.

Demonstrate the presence of the current which is induced by connecting one galvanometer directly to another, preferably an identical instrument, and rocking one of them.

If a hand generator or magneto is available, have a student turn it without having it connected to a load, then make connection so that the device must supply a current. If the power demand is heavy, this reaction will be apparent to the class. Have the student describe the relative difficulty of turning the generator. This emphasizes the fact that Lenz's Law is a special statement of the law of conservation of energy.

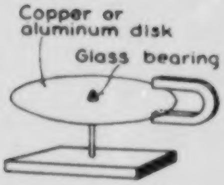
3.59. EDDY CURRENTS AND LENZ'S LAW



Support an aluminum cup *A* or pie tin *B* on a sharp point. The cup may be a tube or coil shield from an old radio, or even a thimble. In either case, locate the center as accurately as possible and make a dimple with a center punch. The support may be a large nail driven through a block of wood, and ground sharp. Paint a distinguishing mark on the side of the cup or pan, so that its rotation can be easily seen. Suspend a strong magnet above so that it clears by a quarter inch, twist the cord and let it unwind, spinning the magnet. The cup will turn in the same direction. If there is some question about air currents turning the cup, hold a card between magnet and cup.

In a variation on this, the magnet may be mounted on a rotator with its poles up, or on a phonograph turntable, with a disk of aluminum supported above it by a thread through the center.

3.60. EDDY CURRENTS AND MAGNETIC BRAKE



a. Cut a disk of copper or aluminum and equip it with a glass bearing at the center. A short piece of glass tubing is sealed off at one end, and the other end slightly flared. It is then pushed through a hole in the center of the disk, held in place if necessary by wrapping a rubber band around it above the disk. The disk may be supported on a point, and set spinning by twirling the glass bearing between the fingers. The friction should be very low, so that the disk will decelerate very slowly. Now hold a strong horseshoe magnet so that its poles straddle the spinning disk, and note the braking effect. A *paint streak along a radius* makes the edge of the disk easier to see and makes its deceleration more evident.

b. Pivot a strip of sheet aluminum on a nail so that it can swing freely as a pendulum. While it is swinging, place a strong alnico magnet so that the path of the moving metal strip crosses the field of the magnet. The motion of the aluminum strip is stopped very quickly.

3.61. THE D.C. GENERATOR

The dissectible motor of the "St. Louis" type, or of the sort designed for demonstration purposes can be used to show the necessary features of generators. A zero-centered galvanometer is connected to the brushes, and the armature is spun with the fingers.

The brushes should first be placed in contact with the slip rings, pointing out the alternating nature of the induced voltage in the armature and the factors which determine its amplitude and frequency. The brushes are then moved to contact the commutator, and its rectifying function demonstrated and discussed.

3.62. GENERATORS AND LENZ'S LAW

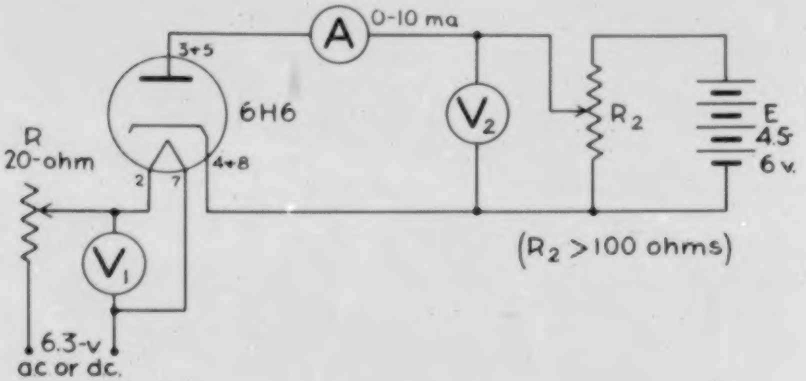
Two small motors, each having both a commutator and slip rings on the shaft, can be coupled together by a rubber band. One motor can then be used to drive the other as a generator. The generator will usually supply enough power to light a flashlight lamp. Emphasize the energy transformations. Use an ammeter and a voltmeter in each circuit to measure the power input and output. Discuss the losses.

When the combination is running freely at full speed — short the generator. The added load will cause an obvious reduction in speed.

An oscilloscope may be used to show the wave form of the generator output when supplying d.c. and then using the commutator as a pulley when supplying a.c. Emphasize the function of the commutator as a rectifier. The generator output should be attached to the vertical input for this demonstration.

3.63. THERMIONIC EMISSION AND THE DIODE

a. Show the dependence of electron emission on cathode temperature. The 6H6 dual diode is especially recommended for this activity because of the low plate voltages required. Half the tube may be used, or the two parts may be operated in parallel as the pin numbers in the diagram illustrate. A battery of 3 or 4 dry cells will suffice for *E*. Any other diode or triode can be used, with appropriate changes in voltages and meters. To use a triode, connect the grid to the cathode.



In this part of the activity, V_2 and the plate potentiometer are not needed and may be omitted. Connect the plate through the milliammeter directly to the positive terminal of the plate supply.

Control the cathode temperature with R and use the readings of V_1 as an indirect indication of the temperature. Show that the plate milliammeter readings and therefore the electron emission from the cathode depend on the cathode temperature.

b. Setting the heater voltage at its rated value, and using R_2 and V_2, show the dependence of plate current on plate voltage. Note that a small plate current exists even when the plate is connected directly to the cathode.

c. Reverse the connection to the battery and show that electron current does not cross the tube when the plate is negative. Make clear the fact that this unidirectional conductivity is the property that permits the use of a diode as a rectifier.

d. If desired, a sequence of readings can be taken in step and a graph plotted, showing the relationship between the plate current and plate voltage.

3.64. CATHODE RAYS

Scientific equipment companies offer several types of demonstration cathode-ray tubes. The most useful type directs a thin ribbon of rays against a long fluorescent screen, so that the beam's path is made visible. The tube is operated by an induction coil. If the glow is general, rather than a clear trace, reverse the connections to the coil.

Bring a horseshoe magnet down over the tube to straddle it and note the direction of beam deflection. Reverse the magnet to make the beam deflect the other way. Compare the motion of the beam to the motion of a current-carrying conductor in a magnetic field. Apply Fleming's rule to demonstrate that the charge on an electron is negative.

If the magnet is brought toward the tube from the rear, the beam can be bent into the screen or away from it—erasing the trace.

CAUTION: Some cathode-ray tubes of this type emit X-rays which are harmful. The tubes and the induction coil used for demonstrations should be checked while operating, to determine the extent of X-ray emission. Local health departments will check equipment upon request.

3.65. DEMONSTRATING THE CATHODE-RAY TUBE WITH AN OSCILLOSCOPE

An oscilloscope can be used to illustrate the basic operation of the cathode-ray tube.

a. Turn the sweep off and show the formation of the spot of light by the beam of electrons striking the phosphor coating on the screen of the tube.

b. Show how the brightness of the spot is influenced by the voltage of a control grid. Point out that this control grid regulates the electron current in the beam very much as does its counterpart in a radio tube.

c. Demonstrate the deflection of the beam horizontally and vertically by varying the settings of the position controls. Explain how this is done by changing the voltage of the deflection plates.

d. Bring a strong magnet near the spot to show that the beam can be deflected magnetically. Apply Fleming's hand rule to show that the beam is indeed a stream of negative charges.

e. Show that the sharpness of focus of the beam can be controlled and draw attention to the similarity to the focusing of light. Point out that the focusing of electrons may be done magnetically or electrostatically.

f. In some oscilloscopes the lowest sweep frequency clearly shows the motion of the spot across the screen. Gradually increase the frequency to show how such a motion may cause what appears to the eye to be a steady line.

g. The formation of a pattern can be made clear by using an alternating voltage on the vertical input with the internal sweep turned off so that a vertical line is formed. Then, using the horizontal position control, sweep from one side to the other manually.

h. Discuss the process of combining horizontal and vertical sweeps to produce a series of horizontal lines, and the simultaneous variation of brightness to produce a picture, as in television.

i. See the discussion of the oscilloscope in the Introduction.

AREA FOUR

RADIATION PHENOMENA

4.01. THE PHOTOELECTRIC EFFECT

A large Braun electroscope can be used to demonstrate photoelectric effect. This electroscope is recommended because it requires a minimum of set-up time for class demonstration. Cut and bend small "ears" on a 3-inch plate of zinc, so that it can be clipped directly to the knob of the electroscope. A strong source of ultraviolet light such as an ultraviolet lamp or a carbon arc with the glass lens removed can be used as the illumination source. *CAUTION: Be sure that your eyes and those of your students are adequately protected from the ultraviolet light.* A large piece of plate glass should be set up between the apparatus and the class as a shield. The instructor should wear protective eye glasses.

Burnish the plate with a piece of fine sandpaper or emery paper to remove any oxide which may have formed on the surface and clip the plate to the knob of the electroscope. Charge the electroscope negatively. Determine the rate at which the electroscope discharges. Recharge the electroscope and illuminate the zinc with ultraviolet light.

A comparison of the discharge rates should show that the ultraviolet light emission increases the discharge rate of the zinc plate.

Charge the electroscope positively and illuminate the zinc with ultraviolet light. Note that the ultraviolet does not affect the discharge rate.

With the electroscope neutral, shine ultraviolet light on the zinc plate and have pupils explain why the electroscope *does not* acquire a positive charge by this technique.

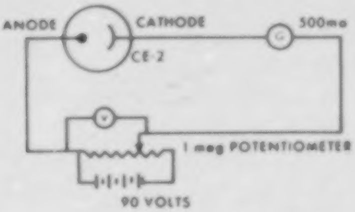
Charge the electroscope negatively and try to increase the discharge rate by shining an incandescent flood lamp on the zinc plate. The discharge rate of the electroscope will not be affected appreciably by the lamp because the photons of longer wavelengths do not have sufficient energy to free the electrons.

Show the relative transparency of ordinary plate glass and clear quartz to the ultraviolet waves by noting the rate of discharge of a negatively charged electroscope when each of these materials is placed between the light source and the zinc plate. Glass absorbs almost all of the ulrraviolet radiations but quartz is transparent to the ultraviolet light.

4.02. PHOTOCURRENT IN A GAS-FILLED TUBE

A simple demonstration of the photoelectric effect consists of focusing visible light from a flashlight or an incandescent lamp on the cathode of a CE-2 photoelectric tube connected in series with a galvanometer as shown in the diagram below. The cathode of the argon filled tube is cesium-coated and sensitive to electromagnetic radiation in the visible range. It operates with a minimum anode voltage of 45 volts and a maximum of 90 volts. (*Do not exceed 80 volts in this circuit.*) The sensitivity of the cell varies with the anode voltage from 125 to 200 microamperes for each lumen of light spread over the cathode.

Modification of this circuit can be made so that a sensitive relay can be utilized to trip auxiliary circuits in order to operate counting devices, motors, or any audible signal. Commercial devices of this type may be used for opening doors, counting traffic, or operating as an intruder detector.



4.03. PLANCK'S CONSTANT

The relationship between the maximum energy of photoelectrons and the frequency of the incident light is the classical means for determining Planck's constant. The next four activities 4.04, 4.05, 4.06, and 4.07 provide an experimental means for obtaining the data.

In activity 4.04 inexpensive means of isolating four distinct and well-known frequencies of the mercury spectrum are given. The current produced by photo-tubes is very small. Therefore, an electrometer circuit which may be used to measure such currents is described in 4.05.

The circuit for measuring the maximum kinetic energies of photoelectrons is described in 4.06. The determination of Planck's constant is discussed in 4.07. A related activity, 4.08, deals with the work function of the photoemissive surface.

4.04. MONOCHROMATIC LIGHT SOURCES FOR PHOTOELECTRIC EXPERIMENTS

Light of a known wavelength is required for a quantitative determination of Planck's constant. Some techniques for obtaining monochromatic light are given on the next page.

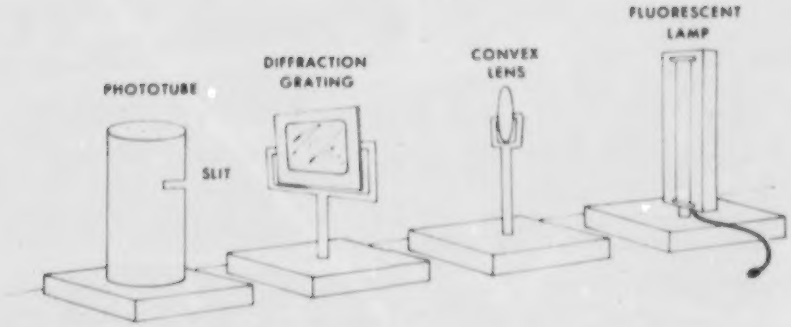
a. Filters. Gas-filled spectrum tubes have characteristic spectra. If the spectral lines are widely separated, much of the unwanted frequencies may be absorbed. Filters of known transmittance which will pass the desired frequencies may be obtained commercially. Special filters are available which isolate the four principal lines in the visible portion of the mercury spectrum. For those who wish to assemble their own sets, the numbers of the Kodak filters are given.

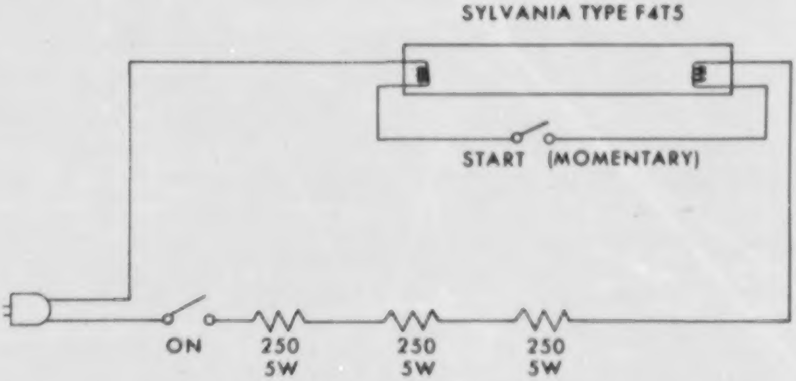
To Isolate the Principal Spectral Lines [illegible] Mercury

Color	Wavelength		Frequency (sec^{-1})	Kodak Filter No.
	Å	mu		
Yellow	5780	578	5.19×10^{14}	22 Wrattan
Green	5460	546	5.50×10^{14}	74 Wrattan (or 77 cemented glass)
Blue	4360	436	6.88×10^{14}	50 Wrattan
Violet	4050	405	7.41×10^{14}	2C Wrattan (Transmits violet and longer wavelengths also)

Colored cellophane and inexpensive plastic filters are useful for teaching color addition and subtraction but they are not suitable for spectral measurements because their transmittance characteristics are variable.

b. Diffraction grating. If a dark room is available for experiments, the four principal mercury lines may be dispersed into separated lines using a diffraction grating as shown in the diagram on the next page. The phototube is covered with aluminum foil and a narrow slit is cut to admit only one of the spectral lines at a time. Raising or lowering the phototube will permit a choice of the four mercury lines to use for quantitative measurements and comparisons. A high pressure mercury vapor lamp and slit may be used for the light source if it is available or an inexpensive 6-inch long fluorescent lamp may be connected to a homemade fixture which uses three 250-ohm, 5-watt resistors for ballast as shown in the illustration. The resistors should be exposed to permit heat dissipation. A plastic replica diffraction grating has sufficient resolution to isolate the principal mercury lines but more expensive gratings will provide a brighter spectrum and are recommended for class demonstrations where there is little time for adjusting and manipulating the apparatus.

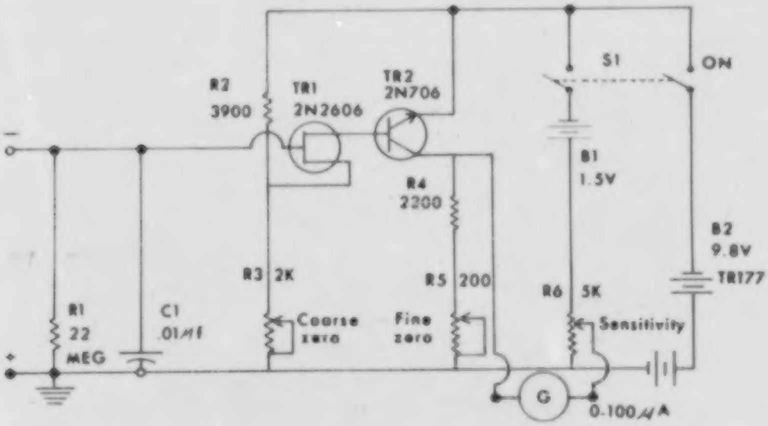

FLUORESCENT LAMP
DIFFRACTION GRATING
CONVEX LENS
PHOTOTUBE
SLIT


SYLVANIA TYPE F4T5
START (MOMENTARY)
ON
250
5W
250
5W
250
5W

4.05. ELECTROMETER FOR MEASURING PHOTOCURRENT

Ordinary laboratory galvanometers are not sensitive enough to detect the current in a phototube circuit, which is on the order of 10^{-9} ampere. Sensitive galvanometers or electrometers are available from scientific supply houses for this purpose. A galvanometer having a range of 100 microamperes can be used to detect photocurrent if a d.c. amplifier is connected to the input terminals. Circuits for constructing these amplifiers have been published in professional journals such as the *American Journal of Physics* and *The Physics Teacher*. One of these circuits, which consists of a two-stage transistor amplifier, is reproduced in the diagram on the next page.

The circuit contains three carbon resistors, a capacitor, three adjustment potentiometer, and a switch. It is powered by two small batteries and the whole assembly (except for the external galvanometer) is extremely compact.



This electrometer does not have balanced circuits. Therefore, it should be turned on at least 5 minutes in advance to allow the circuits to stabilize.

4.06. PHOTON ENERGY

The energy of photons may be determined by allowing a beam of light to strike a metal surface and measuring the energy of the photoelectrons emitted. A circuit consisting of a vacuum phototube, such as the RCA type 929, a 3-volt battery, a voltmeter, a sensitive electrometer (see 4.05) and a variable resistor can be used for this demonstration. If the opposing field is not too great, shining a light on the cathode of the phototube liberates electrons from the photosensitive surface. The electrons are collected by the anode of the tube. They flow through the galvanometer and return to the cathode completing the circuit. Applying a reverse voltage by means of the battery and the variable resistor reduced the kinetic energy of the electrons. The opposing voltage is increased until the galvanometer indicates that all of the electrons have been stopped and the current is zero. At this point, the voltmeter reading is recorded and the kinetic energy of the most energetic electrons is determined by multiplying the charge on the electron (1.6×10^{-19} coulomb) by the voltage.

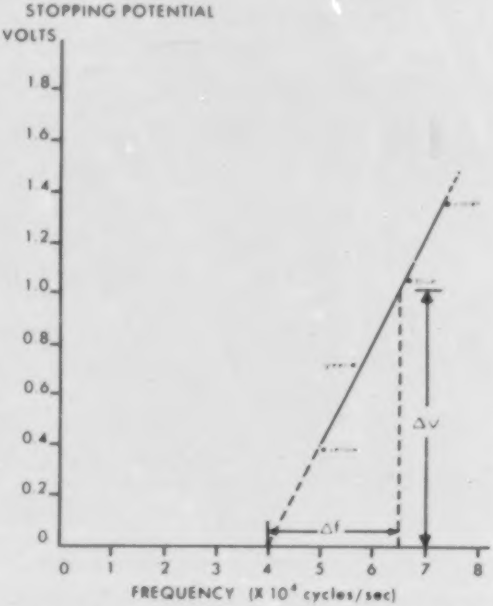
The energy of the original photon was expended in two ways: part of it supplied the electron within the metal with sufficient energy to escape from the surface of the cathode (work function energy); the remainder provided the kinetic energy of the electron.

The 929 phototube has a cesium covered cathode which has a work function of 1.9 electron-volts. When this value is added to the kinetic energy that was determined with the apparatus, the total energy supplied by the photon is known. Using different sources of monochromatic light, it will be found that there is a direct relationship between the frequency of the light and the energy of the photons.

It should be noted that an ordinary laboratory galvanometer is not sensitive enough to detect the small photocurrent (in the order of 10^{-7} ampere) produced by the phototube. If a suitable galvanometer is not available, it may be constructed by following the directions given in Activity 4.05.

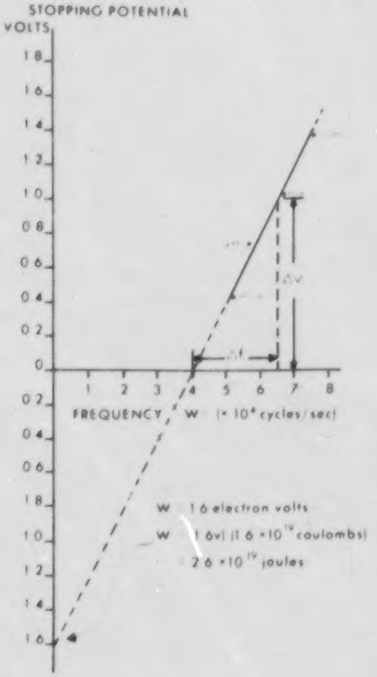
4.07. PLANCK'S CONSTANT AND THE PHOTOELECTRIC EFFECT

The photoelectric effect provides empirical evidence that the energy of a photon is equal to its frequency multiplied by Planck's constant. After having determined the energy of light of a known frequency in the mercury spectrum (4.04) calculate h using the relationship, E = hf, where E is the photon energy in joules, h is Planck's constant, and f is the frequency of the photons in cycles per second. If time permits, repeat the procedure using different frequencies of light to compute Planck's constant. If the work function of the phototube cathode is not known, Planck's constant may be determined by measuring the stopping potentials associated with each of the four principal lines in the mercury spectrum (Activity 4.04) and plotting a graph of stopping potential as a function of frequency as shown in the illustration. Planck's constant is then determined by multiplying the charge on the electron (1.6×10^{-19} coulomb) by the slope of the curve.



4.08. WORK FUNCTION AND THRESHOLD FREQUENCY OF A PHOTOELECTRIC EMITTER

The minimum energy that is required for a photon to release electrons from a metal is sometimes called the work function. To measure the work function, a graph is plotted according to the instructions given in Activity 4.07 of the stopping potential versus photon frequency. The work function is found by multiplying the charge on the electron (1.6×10^{-19} coulomb) by the voltage at the point where the curve intercepts the y axis. The work function may also be calculated by multiplying the threshold frequency by Planck's constant.



4.09. PHOTON-PARTICLE COLLISIONS

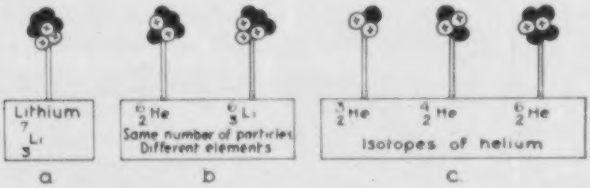
Pair production, Compton scattering and various other types of particle and photon interactions have been photographed in large bubble chambers at universities and at AEC facilities. These photographs are available for stereo viewing and mathematical analysis from scientific supply houses. Distances of travel may be closely estimated by referring to fiducial marks and enlargement data that are furnished with the photographs. The momentum of a charged particle may be determined by using the relationship:

$$p = qBr$$

Where: p is the momentum in Kg-m/sec
q is the charge in coulombs with the basic charge equal to 1.6×10^{-19} coulomb
r is the radius of the track curvature in meters
B is the magnetic field of Webers/m^2

4.10. NUCLEAR MODELS

Static models can be constructed and exhibited in order to help clarify certain features of nuclear structure. Ping-pong or styrofoam balls representing nucleons are large enough to be clearly visible. Some may be painted a solid color to represent neutrons, and others marked with a large plus sign to represent protons. Each nucleus should be clearly labeled.



a. Cement together three protons and four neutrons to represent the most abundant isotope of lithium ($^{7}_{3}Li$). Use this model to show the meaning of atomic number and the contribution of neutrons to the atomic mass.

b. Exhibit a helium-6 nucleus with one representing lithium-6 in order to emphasize the fact that the number of protons, rather than the total mass number determines the nature of the element.

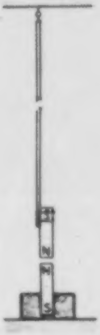
c. Show three isotopes of helium, $^{3}_{2}He$, $^{4}_{2}He$, $^{6}_{2}He$, stressing the fact that they are different forms of the same element, the number of neutrons not influencing the chemical nature of the material.

d. Identify the $^{4}_{2}He$ as an alpha particle—in itself a sort of nucleon. Use this nuclear model later in the study of radioactivity.

4.11. A SCATTERING ANALOG

The repulsion described by the inverse square law that causes scattering of low velocity particles and makes necessary high velocity particles to cause changes in nuclei can be illustrated by the similar repulsion between magnet poles.

A strong alnico bar magnet is attached rigidly to a light wooden rod, which hangs freely from the ceiling. A similar magnet is mounted directly under its rest position so that the two poles barely clear. Now, if the hanging magnet is drawn aside and released, it will be repelled back toward its starting point, and cannot pass directly over the fixed magnet unless given more velocity by starting from a greater distance.



If the fixed magnet is moved aside slightly, the swinging magnet will be deflected in a hyperbolic path analogous to the alpha particle scattering by gold nuclei in Rutherford's experiment.

Circular and elliptical orbits, such as those of electrons in atoms, or planets in the solar system, can be simulated if the fixed magnet is reversed.

4.12. THE BALMER SERIES AND PLANCK'S CONSTANT

The Bohr relationship for the energy levels of the hydrogen atom provides the basis for a determination of Planck's constant.

Determine the wavelengths of the four principal lines in the hydrogen spectra (a part of the Balmer Series), by using a diffraction grating (see Activity 2.59).

Solve for Planck's constant by using the following form of the Bohr relationship:

$$h = \frac{13.6\ \lambda}{c} \left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$

Where h = Planck's constant
λ = The wavelength of the observed line in meters
c = 3.00×10^8 m/sec.
n = 2 for the red line
n = 3 for the blue-green line
n = 4 for the blue-violet line
n = 5 for the violet line (This line is not very intense and may be invisible under other than ideal circumstances.)

The value obtained may be converted to joules by multiplying by 1.6×10^{-19} joule/e.v. Values obtained should be quite close, within two or three significant figures, of the accepted value, 6.63×10^{-34} joule-second.

4.13. GEIGER TUBE ANALOGY

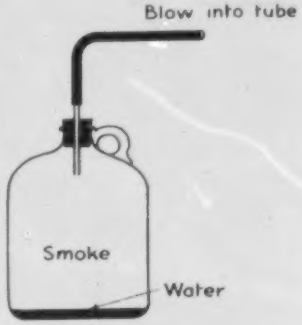
An avalanche of electrons resulting from a single ionization in a strong electric field produces the impulse which operates a Geiger counter. This can be simulated with a smooth panel of plywood or masonite or a piece of window glass, and some marbles. The plate is tilted gently to represent the field, and electrons associated with molecules of gas are represented by an array of marbles on its surface. Pieces of cellulose tape on the glass make enough of an irregularity to prevent the marbles from rolling. If plywood or masonite is used, little depressions can be made with the tip of a quarter-inch drill.

Now, when one of the molecules in the top row is "ionized" by tipping a marble out of its depression, it rolls down the plane and successively "ionizes" other "molecules," causing a cascade of marbles to arrive at the bottom of the plane. In similar manner a single electron may produce a cascade of electrons which will reach the central wire of the Geiger tube.

4.14. THE PRINCIPLE OF THE WILSON CLOUD CHAMBER

In the Wilson cloud chamber, the saturated gas is cooled below its dewpoint by a sudden expansion. This principle may be illustrated by showing the formation of cloud droplets on dust or smoke particles when saturated air is suddenly allowed to expand. Of course, in a cloud chamber, the condensation nuclei are ions, formed in the path of the charged particles. Inexpensive cloud formation flasks with rubber bulbs are available from scientific supply houses specializing in earth science apparatus.

Place a small amount of water in the bottom of a large bottle or jug and fit a one-hole stopper with about a foot of rubber tubing. Drop a lighted match into the bottle to introduce condensation nuclei. Place the stopper in the bottle, blow hard on the rubber tubing to raise the pressure in the bottle, and then let the stopper pop out. Successive increases and decreases of pressure make the fog



appear and disappear. Discuss adiabatic temperature changes and the relationship between absolute humidity at saturation, and the temperature.

Clear the air in the bottle of smoke and repeat to show the necessity for condensation nuclei. In a cloud chamber, the condensation nuclei are ions, formed in the path of the charged particles.

This demonstration shows the principles which make the operation of the Wilson cloud chamber possible, and illustrates the condition essential to natural cloud formation.

4.15. DIFFUSION CLOUD CHAMBER

The continuous-acting diffusion cloud chamber is suitable for individual project work or for classroom demonstration use. With patience and care, very rewarding observations can be made. Simple as well as elaborate versions are listed in science supply catalogues. These directions describe a cloud chamber which can be made, using commonly obtainable materials and will also suggest several possible refinements.

The chamber is a large diameter jar, of not very great height, having clear glass sides and bottom and a capacity of at least a pint. It should have a tight-fitting metal screw cap. Peanut butter sometimes comes in a jar of this description. A ring of blotting paper or felt is cemented around the sides of the jar near the bottom. The inside of the cap is either painted flat black or covered with black material, as a background for viewing the traces. The blotting paper is saturated with alcohol, and the cap screwed tightly onto the jar. The whole assembly is then inverted on a cooling platform of dry ice, so that the cooling agent makes good contact with the metal cap. Supporting the jar in a crushed dry ice-alcohol mixture works well. The chamber should be illuminated from the side by a beam from a flashlight or slide projector, directed so that it grazes the cap. A mist quickly forms in the jar as alcohol vapor condenses on dust particles, and observation of the "rain" that results is in itself worthwhile.

After some time this mist clears up, and a supersaturated layer forms above the cold surface of the jar lid. When high energy particles from cosmic rays enter this zone, they form trails of ions on which condensation takes place, forming visible cloud traces.

It is possible to increase the display by placing a weak source of alpha particles in the chamber at the time it is assembled. This source should be supported just above the cooling surface. It may easily be made by putting a drop of plastic cement on the point of a thumbtack and then dipping it, before the cement hardens, in material scraped from the dial or hands of a luminous dial clock.

It is desirable to add some provision for an electric field to clear the chamber of unwanted ions. This is provided by pressing a wire ring into the jar just below the blotting paper and making connection to this wire through a small feed-through insulator in the cap. Use this wire and the metal cap to provide a field of 300 volts or more. Do not use line voltages, 300-volt dry batteries are available.

4.16. DETECTION OF RADIATION WITH FILM

The radioautograph and similar methods of studying radioactivity depend on the sensitivity of photographic film to the radiations from radioactive substances. The principle involved can be shown with Polaroid camera film (Pola Pan type 57) using a luminous dial watch or clock or a gasoline lantern mantle which contains thorium as the source of radiation.

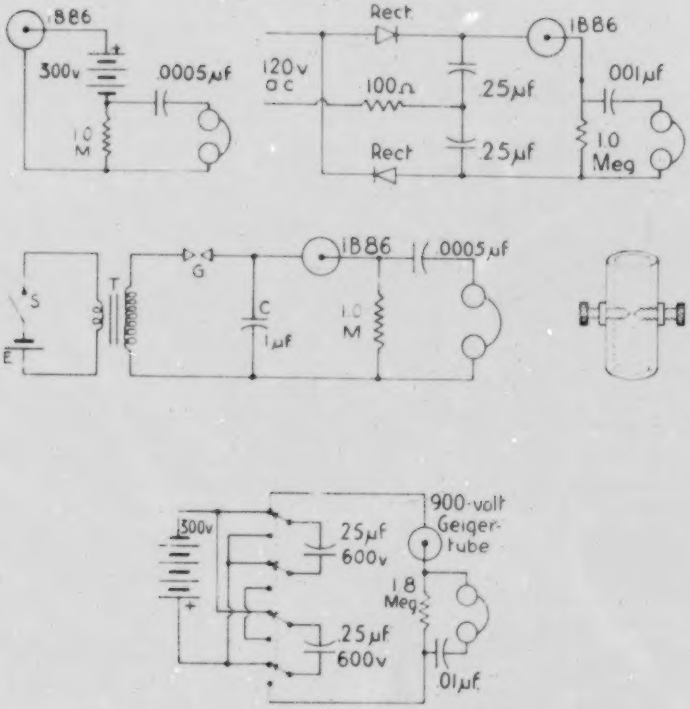
A metal object with a recognizable outline, such as a key or washer, is placed on an unopened film envelope, and the watch, face down, placed on top of it. The combination is placed where it will not be disturbed for several days. Then the print is developed by rolling the film so as to squeeze the chemicals across the face of the print. The outline of the object can be seen where the film was exposed to the radiations.

The length of exposure needed depends on several factors. Luminous paint varies greatly in its activity, and a strong source may produce an adequate exposure in 48 hours. The crystal or glass of the timepiece absorbs some radiation and increases the distance between source and film, so that better exposures are obtained by using an exposed face. The sensitivity of the film has a great effect. X-ray, or 3000 speed Polaroid film works best. A wrist watch, with crystal in place, produces a visible exposure of Verichrome film in about eight days.

4.17. CONSTRUCTION OF GEIGER COUNTERS

A Geiger counter is essential for demonstrating some of the most fundamental concepts of nuclear energy. Fortunately, the construction of simple and effective counters is a possible project for the high school laboratory. In their simplest and least expensive form, such homemade instruments give an audible indication of gamma radiation. At somewhat greater expense and with more complex circuits, it is possible to amplify the clicks, to detect beta particles as well as gamma rays, and to provide visual indicators such as a neon flasher and a rate meter. Magazines such as *Radio and Television News* and *Popular Electronics* have provided construction details for building such instruments. Inexpensive kits for the construction of Geiger counters are on the market.

Geiger Counter Circuits


1B86
300v
.0005µf
1.0 M
Rect
120v a c
100Ω
.25µf
.25µf
Rect
1B86
.001µf
1.0 Meg
S
E
T
G
C
1µf
1B86
.0005µf
1.0 M
300v
.25µf 600v
.25µf 600v
900-volt Geiger-tube
1.8 Meg
.01µf

The simplest arrangement shown in the diagram above uses a 300-volt counter tube, such as the Victoreen 1B86 which is sensitive to gamma rays. The power supply may be a 300-volt battery or one of the circuits shown above. Counts are audible as rather faint clicks in the earphones. The same circuit can be used to operate a 900-volt tube such as the 1B85, which is sensitive to both beta and gamma rays, using three 300-volt batteries in series.

High voltage batteries are costly, however, and it may be desirable to use less expensive means of obtaining the voltage. If portability is not important, the 120-volt a.c. powerline can be used as a source. The very inexpensive and compact power supply in diagram 4.17b uses two small crystal rectifiers in a voltage doubler circuit to provide 300 volts. Except for the counter tube and the earphones, this can be built for less than $5.

A simple portable arrangement produces the high voltage by charging a capacitor, using the voltage induced in the secondary of a transformer when the primary circuit is broken. In diagram 4.17c T is a radio output transformer. A small flashlight cell is connected to its low-voltage winding through a normally open, spring-return snap switch (S). The high voltage induced in the secondary when the switch is opened charges capacitor C through a spark gap G. After a dozen or so snaps of the switch, the voltage on the capacitor is sufficient to operate the counter tube. The counter then operates for a period of time determined by the quality of the capacitor and the insulation of the high potential portion of the circuit. When the counter stops working, it is started again by snapping the switch. The spark gap is easily constructed as shown in diagram 4.17d. A short piece of plastic tubing holds two sharpened machine screws with their points about 1/2 mm. apart. The gap is not very critical. The fundamental nature of this circuit makes it an attractive student project.

Another instructive method of obtaining the high voltage adds the charges on capacitors to that of a battery by connecting them in series. One version of this circuit is shown on page 155. The switch is a 4-pole, 2-position, spring-return switch. In the position shown, the capacitors are charged by the battery. When the switch is returned to the other position, the two charged capacitors are placed in series with the battery, providing 900 volts for operation of the tube. The counter then continues to work for several minutes, until its sensitivity drops off as the charge on the capacitors declines, at which time a flip of the switch recharges them.

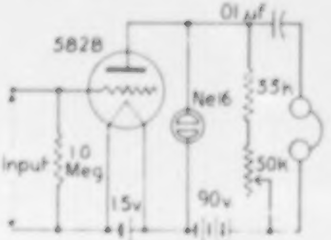
4.18. AMPLIFYING THE SIGNAL FROM A GEIGER COUNTER

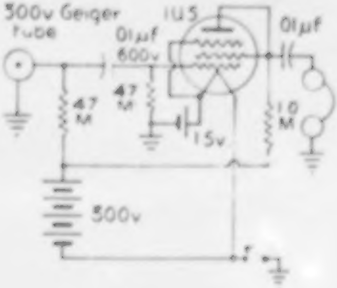
Almost any available amplifier can be used in place of the headphones of the preceding circuits to produce increased signal volume. One of the most available audio-amplifiers is a school tape recorder. Patch the earphone leads into the input jack of the recorder and activate the monitor or "R.A." switch. Recording level meters on some recorders may be used to compare the relative activity of sources with greater accuracy than listening to signals. As an alternative, three interesting circuits are presented here.

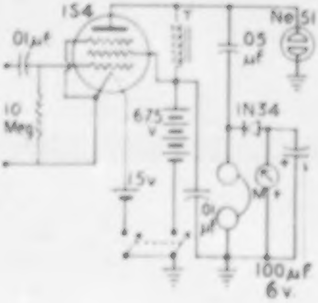
The first of these, shown on page 157, not only raises the signal level, but also causes each click to flash a neon light. The tube is a filament type triode, and if compactness is desirable, the Victoreen 5828 is suitable. Other triodes can be used, with the necessary changes in circuit values. A small speaker can be operated by this tube if the neon lamp is removed and an output transformer substituted for the fixed and variable resistors of the plate circuit.

The amplifier, shown in the diagram is interesting, and especially suitable for a portable instrument because it uses as its "B" voltage the high voltage supply of the Geiger tube.

It is also possible to operate a count-rate meter from a single tube amplifier. In the circuit in diagram 4.18c, T is the primary of an output transformer. M is a 0-500 μa. meter, for which a more easily obtainable 0-1 ma. meter may be substituted with some loss of sensitivity.


5828
01 μf
Ne16
55k
50k
Input
1.0 Meg
15v
90v


300v Geiger tube
1U5
01 μf
600v
01 μf
4.7 M
47 M
15v
1.0 M
300v


1S4
01 μf
10 Meg
T
05 μf
Ne 51
67.5 V
1N34
15v
01 μf
M
100 μf 6 v.

4.19. USING A GEIGER COUNTER

The type of counter which produces an audible signal or flashes a light is useful mainly as a detector of radioactivity. Its use for measurement is limited to low activity situations where individual pulses can be counted. After some experience with high activity sources, the operator may be able to make rather crude judgments of the amount of radiation by the sound. Most homemade counters will be of this type, the kind we shall call an "audible counter."

The more elaborate type of counter which incorporates a count-rate meter is better suited to quantitative use. All of the observations possible to an audible counter can be made with a rate-meter counter and it can, in addition, give a quick and reasonably accurate indication of the number of counts per minute up to many thousand.

While most of the experiments that follow have been developed with the rate-meter counter in mind, the audible counter has many desirable classroom characteristics, and is adequate for a variety of instructive procedures. Some of these are suggested here:

a. Demonstrate the radioactivity of various materials.

- The school mineral collection may have several radioactive samples. Place a known active sample among inactive pieces, and show how a counter can be used to locate radioactive ore.
- Uranium salts borrowed from the shelves of the chemistry stockroom will show strong activity.
- Bring the dial of a luminous watch near the tube and note the response.
- Orange and yellow colored pottery often owes its bright color to uranium salt. Such a piece will cause a strong response in a Geiger counter.
- The Welsbach mantles used in gas or gasoline vapor lamps contain thorium - a source of radioactivity.

b. Activity 4.24, a study of the statistical nature of nuclear physics measurements, is best done with a scaler or a suitable counter and stopwatch.

c. Scalers, available from scientific supply houses, add flexibility and range to the experiments that can be performed and may improve quantitative results.

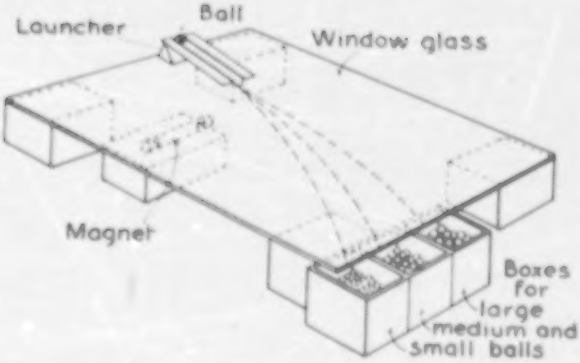
d. The variation of radiation intensity with distance (Activity 4.25) can be measured with an audible counter. The distances must be great enough to permit counting of individual clicks, and the background count must be subtracted from each measurement. To increase accuracy, counting must be done over as great a time period as possible.

e. The absorption of radiation by various materials can be shown qualitatively by use of an audible counter. Measurements as described in Activity 4.30 can also be made.

f. The reflection of beta particles as described in Activity 4.28 can be shown satisfactorily with an audible counter and the procedure of Activity 4.29 is also possible.

4.20. A MODEL MASS SPECTROGRAPH

The separation of isotopes of an element by a mass spectrograph can be illustrated in analogy by using different size steel balls. A piece of window glass is mounted horizontally. A strong magnet is placed under it, close to the glass. The balls are



launched from a small incline and roll across the glass on a path which passes near the magnet. The large balls are deflected less than the small ones so that boxes can be placed at the edge of the glass, each catching a different size ball.

The inclined launcher is folded from a couple of file cards and is attached to the glass with wax or rubber cement. Final adjustment is made by shifting the position of the magnet. The balls can be released in any order, but not too close together, as the induced fields of consecutive balls interfere with their paths.

4.21. BINDING ENERGY

Calculations of the nuclear binding energy are not too difficult for high school physics students and can contribute to an appreciation of the equivalence of mass and energy and to an understanding of the source of energy in both fusion and fission reactions.

After a discussion of isotopes and how the mass spectrograph is used to measure isotope masses, it should be shown that the measured mass of a nucleus is less than the total mass of neutrons and protons presumably composing it. This apparent loss of mass is identified as the binding energy which prevents the nucleus from flying apart.

For convenient reference, a table of isotopes, including the results of some computations is given: (Note that the commonest isotopes of helium, carbon, and oxygen are listed separately. Accurate measurement shows that a periodicity occuring in isotopes whose mass number is divisible by four throws these off the smooth curve.)

Isotopes		Mass (a.m.u.)	Mass Number	Number of Protons	Number of Neutrons	Binding Energy Per Particle (a.m.u.)
Proton	$^{1}_{1}H$	1.0081	1	1	0	
Neutron	$^{1}_{0}n$	1.0089	1	0	1	
Deuterium	$^{2}_{1}H$	2.0147	2	1	1	.0011
Helium	$^{3}_{2}He$	3.0170	3	2	1	.0027
Lithium	$^{6}_{3}Li$	6.0170	6	3	3	.0057
Lithium	$^{7}_{3}Li$	7.0182	7	3	4	.0060
Boron	$^{10}_{5}B$	10.0161	10	5	5	.0069
Carbon	$^{13}_{6}C$	13.0075	13	6	7	.0079
Oxygen	$^{17}_{8}O$	17.0045	17	8	9	.0084
Magnesium	$^{24}_{12}Mg$	23.9920	24	12	12	.0088
Sulfur	$^{32}_{16}S$	31.9823	32	16	16	.0090
Calcium	$^{40}_{20}Ca$	39.9753	40	20	20	.0091
Nickel	$^{58}_{28}Ni$	57.9593	58	28	30	.0092
Krypton	$^{84}_{36}Kr$	83.938	84	36	48	.0093
Silver	$^{107}_{47}Ag$	106.938	107	47	60	.0090
Barium	$^{138}_{56}Ba$	137.916	138	56	82	.0092
Tantalum	$^{181}_{73}Ta$	180.928	181	73	108	.0089
Lead	$^{208}_{82}Pb$	208.057	208	82	126	.0085
Radium	$^{226}_{88}Ra$	226.10	226	88	138	.0081
Uranium	$^{238}_{92}U$	238.14	238	92	146	.0080
Helium	$^{4}_{2}He$	4.0039	4	2	2	.0075
Carbon	$^{12}_{6}C$	12.0040	12	6	6	.0082
Oxygen	$^{16}_{8}O$	16.0000	16	8	8	.0085

Sample calculation:

Mass spectrograph measurements show the mass of $^{9}_{4}Be$ to be 9.0149 atomic mass units. Since this is composed of four protons and five neutrons, the total mass of its "parts" is:

$$\begin{aligned} 4 \times 1.0081 &= 4.0324 \\ 5 \times 1.0089 &= \underline{5.0445} \\ & \ 9.0769 \text{ atomic mass units} \end{aligned}$$

This is obviously greater than the mass of the nucleus by 9.0769 — 9.0149 = .0620 a.m.u. This mass, which disappeared in the formation of the beryllium nucleus, accounts for the binding energy. A similar computation for heavier nuclei shows greater total mass discrepancy, as might be expected. This does not necessarily mean that they are more strongly bound together, because a greater total binding energy is necessary to hold together the larger number of nucleons.

The binding energy per particle is a more significant quantity. In the case of beryllium, it is: $\frac{.0620}{9} = .0069$ a.m.u. per particle. Similar calculations for other elements reveal a definite pattern, best demonstrated graphically. A broad, but definite maximum exists in the middle of the periodic table. Any nuclear reaction that proceeds toward this peak must result in the loss of mass and the evolution of energy. Such reactions are the fission of uranium, which works from the high end of the curve toward the middle, and the fusion of light elements to form heavier intermediate elements.

Plotting this curve makes an interesting class exercise, not only producing a valuable item for future reference on explaining nuclear reactions, but also removing for the students a regrettable atmosphere of magic which for many of them envelops the whole field of nuclear energy. It is suggested that, after a thorough explanation, each row of students work together as a team to make two or three such calculations in an assigned range, in order to allow time to assemble results and plot the graph.

4.22. SEPARATION OF ISOTOPES BY DIFFUSION

The equipment and procedure of 4.20 can be used to illustrate the fundamental principles of the gaseous diffusion process used at Oak Ridge, Tennessee. In the demonstration described, the difference in mass between air molecuees and fuel gas molecules (especially hydrogen) results in a large difference in their average speeds. Thus the effect is large enough to be used as a demonstration. However, the separation of U^{235} from U^{238} is much less efficient. The uranium is gaseous in the form of uranium hexafluoride, and the molecular weights of the two compounds are 349 and 352 respectively. Since the whole operation depends on the average kinetic energies at the same temperature being the same, the ratio of the velocities is inversely proportional to the square root of the ratio of the masses. Thus the velocities are so nearly the same that rates at which the molecules pass through a porous barrier differ but little, and the process must be repeated a very great many times to achieve a useful enrichment of U^{235}.

A brief consideration of the magnitude of this problem may bring home to the physics students some important ideas.

- The secrets of the nuclear devices, which were of such great public concern, were largely technological rather than scientific.
- Science and technology can progress by enormous leaps when a large team of competent investigators is supplied with appropriate facilities and funds for the solution of a particular problem.
- The rapid development of useful-scale methods of separating uranium isotopes called for many far-sighted decisions on the part of the scientists in charge of the work.

4.23. BACKGROUND RADIATION

Background radiation may result from natural or artificial sources. The earth is continuously being exposed to cosmic rays. Other natural sources of radioactivity are rocks and chemicals. About 1 percent of background radiation is due to fallout. Radium dial wristwatches, and stored radioactive materials cause a background even though they may be some distance from the detector.

The first step in using a counter is to average the background count over a period of at least several minutes each time the counter is used. This is especially true when weak radioactive sources are to be measured.

Background can be reduced by shielding. The simplest way is to use a heavy lead shield made from lead bricks or a lead cylinder.

The accuracy of counting techniques depends on the ratio S^2/B, where S is the difference between the counting rate and the background (or total count minus background), and B is the background. The greater the ratio of the square of the Activity S, to the background, the greater the accuracy.

4.24. STATISTICAL NATURE OF NUCLEAR PHYSICS MEASUREMENTS

Most measurements of atomic and nuclear phenomena are statistical in nature. The random characteristics of cosmic ray observations can be studied as an illustration of this fact.

A Geiger counter is operated with no radioactive source in the vicinity. The erratic counting rate is obvious. Using a stopwatch, or a watch with a sweep second hand, the number of counts in each of, say 50 or 60 five-second intervals is recorded. It will be found that this varies from perhaps none at all to 10 or more. The record may be kept as a series of checks after the numbers representing the number of counts per interval. In the example shown, the most

0	/	5	////
1	𝍸 //	6	//
2	𝍸 𝍸 /	7	//
3	𝍸 𝍸 𝍸	8	/
4	𝍸 𝍸	9	/

probable number of counts per interval is three. By dividing the total number of counts by the number of intervals one can obtain the average number of counts per interval. In this case it is 3.3. This corresponds to about 40 counts per minute.

Then, to illustrate that reliability is only obtained in such measurements by use of a large enough data sample, the number of pulses in a minute can actually be counted several times. It is seen that these results are much more consistent than the counts obtained in the small five-second intervals.

A graph can be constructed to show the statistical distribution of the rates observed.

4.25. VARIATION OF RADIATION INTENSITY WITH DISTANCE

Using a Geiger counter incorporating a rate meter, measure the radiation at various distances from a radium button. It can be shown that doubling and tripling the distance results in respectively one-quarter and one-ninth the original count rate, or the inverse square relationship can be shown by comparing the ratio of the count rates at two different distances with the reciprocal ratio of the squares of the distances.

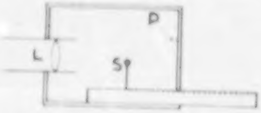
It should be noted that either a low count rate or use of short distances contributes to the inaccuracy of this experiment. If a low count rate must be used, the background count should be subtracted. Short distances yield poor results because the distances to the ends of the counter tube are significantly different from the distance to its center.

4.26. SCINTILLATIONS CAUSED BY ALPHA PARTICLES

a. Luminous paint can be seen in the dark because it contains a tiny amount of radium mixed with the material of the paint. Alpha particles from the radium excite the phosphorescent substance (frequently zinc sulfide) and each encounter causes a burst of light. These individual flashes can be seen with the aid of a magnifying glass. A luminous dial watch should be kept in the dark for a while before the experiment so that the general phosphorescent glow does not obscure the flashes. The observer's eyes must also be adjusted to the dark.

b. Spinthariscopes are sold by scientific supply houses. They are not suitable for class use because they must be used in the dark and the observer's eye must be accommodated to the dark.

c. A homemade spinthariscope can incorporate a useful adjustment not built into the commercial models—control over the distance from source to screen. A small box is selected whose length is somewhat less than the focal length of the magnifying lens *L* to be used. The lens is pressed

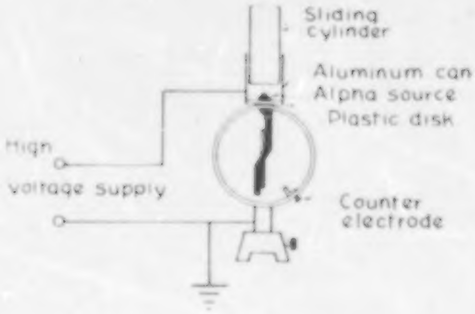


into a short cardboard cylinder, which fits in a hole in one end of the box so that its position can be adjusted for greatest magnification. The other end of the box is removed, painted with shellac, and while still wet, dusted with phosphorescent zinc sulfide. It is then replaced to form the screen *F*. The radiation source *S* is mounted on a stick of wood so that its distance from the screen can be varied, and measurements made by means of a scale printed on the stick. The source is on the head of a pin. It is prepared by cementing to the pinhead a flake from the dial of a discarded luminous watch or clock. The whole apparatus should be as light tight as possible.

When the source is close to the screen, the scintillations are brilliant and numerous. By moving the source, the student can see the reduction in energy of alpha particles as they pass through increased distances in air, and finally observe that there is a limit to their range.

An even better, though somewhat more complex arrangement, would be to use a cover-slip (obtained from the biology department) as a screen, treating one side of it as recommended for the end of the box. This, then, could be mounted *between* the source and the lens, thus permitting the study of alpha particle absorption by filters. A single thickness of ordinary paper will stop all alpha particles. Onion skin and other tissues may be tried.

d. Ionization chamber and pulsating electroscope. An ionization chamber with a sliding cover can be made by removing the ends of an aluminum can which contained frozen orange concentrate. Replace one of the ends with a circular disk of insulating plastic. Slide a cardboard cylinder, which is completely covered with aluminum foil, into the other end. The cylinder should slide easily in the can but it should be snug enough to remain in position when it is released. Drill a hole in the plastic disk which is large enough to admit the knob of the electroscope and mount the disk on the knob as shown in the diagram. Apply a potential of 1,000 volts to 5,000 volts between the isolated can and the body of the electroscope. When an alpha source is placed on the knob of the electroscope, the alpha particles will ionize the surrounding air and the electroscope will slowly charge at a rate that is proportional to the amount of ionized air in the can. The electroscope vane is deflected until the vane makes contact with a counterelectrode which discharges the electroscope. With the voltage constant and the cover of the chamber lowered until it is about 1 cm. above the source, the number of vane deflections per minute is recorded. This is repeated as the sliding cover is raised in steps of 1 cm. It will be found that the oscillation rate of the vane increases as the cover is raised because a greater quantity of air is ionized as each alpha particle is allowed to travel further before being absorbed. When the distance between the source and the cover becomes greater than 3 cm., however, the charging rate will begin to taper off and then will hold constant with increasing distances because the range of the alpha particles has been exceeded.



e. Cloud chamber. An alpha source may be placed in a cloud chamber and photographs of the tracks may be analyzed to determine the range of the alpha particles. Reference lines may be marked on top or base of the cloud chamber to help in measuring distances and a Polaroid camera can make photographs that are developed in a few seconds.

f. Geiger counter. A Geiger tube with a thin mica window can detect alpha particles. To measure the range of the particles, it is convenient to set up the tube and alpha source on an optical bench or along a meter stick. The alpha source should be weak in gamma radiation (such as Po-210) and covered with heavy aluminum foil which has a large pinhole to permit collimated alpha particles to emerge. To find the range of the particles, the tube is gradually moved away from the source while distance vs. counting rate data are recorded. It will be found that the cut-off distance is not sharp because the energies of the particles vary. Absorption by the air changes as its density varies during the experiment. If a piece of cardboard is placed between the source and the Geiger tube, the alpha particles will be absorbed and any indications on the Geiger counter will be due to background radiation and gamma/or beta emissions from the source.

g. Radioassay electroscope. Radioassay electroscopes, which are available from scientific supply companies, consist of a quartz fiber electroscope charged by an internal power supply. The electroscope is then slowly discharged by radiations as they ionize the surrounding air. The rate of discharge may be determined by finding the time that is required for the fiber to cover a given distance (drift) along a calibrated scale. The bottom cover of the chamber should be removed and the electroscope and alpha source should be mounted on a ringstand or some similar support. The electroscope chamber rests on a metal ring which is covered by a piece of thick cardboard which has a 1/4-inch hole in the center to collimate the alpha beam. With the bottom of the chamber about 1 cm. from the source, the drift rate of the electroscope is determined. Then the electroscope is raised in steps of exactly 1 cm. and the drift rates for each position are measured. The background activity is determined by removing the alpha source and measuring the drift rate.

h. If the scaler and pulse coupling network are available, it is possible to obtain data which can be used to draw a graph of intensity as a function of distance. The graph should show a sharp decrease in the intensity of the radiation at the maximum range of the alpha particles.

4.27. IONIZATION OF AIR BY ALPHA PARTICLES

A simple foil leaf electroscope can be used to detect the ionization of air by alpha particles. The electroscope is charged and its rate of discharge measured. Then an alpha source is brought near the knob and it is found that the electroscope discharges two or three times as fast.

For demonstration purposes it is best to project the shadow of the electroscope on the chalkboard or on a screen. Shadow projection can be done by use of a point source of light. An arc spotlight with the lens removed, or a 32-candlepower automobile lamp, operated from a transformer, are satisfactory. Or an effective point source can be produced by focusing the beam from a spotlight with an extra lens and placing the object between this focus and the screen. The lamp, electroscope and screen are lined up so that the shadow of the leaves falls on a scale by which their separation can be measured.

The alpha source can be an alpha-ray tip obtainable from science supply houses, or a speck of material from the dial or hand of a luminous dial watch or clock.

The rate of discharge can be measured by noting the distance moved by the leaves in a fixed time interval, say three minutes, or by timing the motion of the leaves through a given arc. Several interesting experiments can be done with this apparatus.

a. Charge the electroscope and bring a lighted match, candle or gas flame near the knob. The rapid discharge is brought about by the large number of ions produced by the flame.

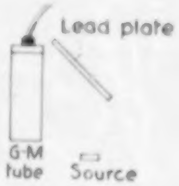
b. After determining the normal rate of discharge of the electroscope, bring the alpha-ray source to within a centimeter of the knob, measuring the rate of discharge again.

c. Show how easily alpha particles are stopped by measuring the electroscope's rate of discharge when one or two layers of paper are between the source and the knob. Most Geiger tubes are not sensitive to alpha particles because they cannot penetrate the glass or aluminum walls of the tube.

d. An approximation of the range of alpha particles in air can be made by measuring the rate at which the electroscope discharges as the distance between the alpha source and the electroscope is increased. Beyond about 4 cm. the rate of discharge will be unaffected by the alpha particles.

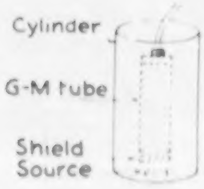
4.28. REFLECTION OF BETA PARTICLES

Beta particles are scattered by a dense material such as lead. A source of beta particles and a Geiger counter which is beta sensitive are necessary for this demonstration. The source is placed near, but at an unfavorable angle to the tube, and the count rate observed. A lead plate is then moved into a position as shown and the increased count rate noted. The effect is not obtained if an aluminum plate is placed between the source and the lead reflector, showing that the observed increase is due to beta particles rather than to gamma rays.



The relative positions of tube and source and the position and angle of the lead plate may be experimented with.

4.29. RELATIONSHIP OF BETA PARTICLE SCATTERING AND THE DENSITY OF THE SCATTERER



A Geiger tube which is sensitive to beta radiation is held in a fixed position with respect to a beta source. A metal shield is interposed to absorb beta particles which might be received directly. In the case of the probes of most commercial counters, the protective metal sheath acts as such a shield. The source may be a radium button or a container of uranium nitrate crystals. Cylinders of cardboard (a mailing tube), of aluminum, and of lead are successively moved into position to surround the probe, and the count taken each time. The aluminum and lead cylinders are easily made by rolling a sheet of the material to the proper shape. The increased scattering by denser materials is revealed by an increase in the count rate.

Note that if the cardboard tube is inserted in the lead tube and the two used together, the rate is less than for the lead alone because of the absorption of beta particles in the cardboard.

4.30. ABSORPTION OF RADIATION

The Geiger tube and radiation source are placed in fixed positions with respect to each other so that the readings of the rate meter are high on its scale. The meter then is read each time after a plate of the absorbing material is placed between them. Continue to add absorbers until the count rate drops to a low value. The absorbers may be of lead, glass, aluminum, cardboard or of any other convenient material of uniform thickness.

A curve may be plotted for each material, showing counting rate as a function of number of layers of absorber. If the tube is sensitive to beta particles these curves show a sudden change in slope at the thickness which absorbs all these particles. Comparison of the thicknesses of the various materials required to reduce the rate to some fraction, say one-half, of the original rate reveals the significance of density.

If it is desired to plot such a curve for gamma radiation alone, the beta rays may be filtered out by about 2 mm. of aluminum placed close to the tube between it and the source.

4.31. DISTINGUISHING BETA FROM GAMMA RADIATION WITH A GEIGER COUNTER

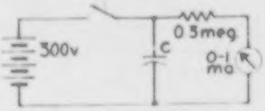
A Geiger counter which is sensitive to both beta and gamma radiation can be used to measure either one alone by separating the two with an external shield. A thickness of about 2 mm. of aluminum will cut out all of the beta rays from ordinary radioactive materials, and cause very little reduction of the gamma ray strength. Readings are taken with and without the shield. The difference in the beta count and the shielded reading is the gamma ray activity.

4.32. EXPONENTIAL DECAY

Some phenomena occur at a rate which decreases exponentially. These phenomena may be used to illustrate the decay pattern of a radioisotope and the concept of half-life. Some of the analogies will furnish data which are similar to actual data obtained with a radioactive sample and a Geiger counter, but it is important to point out that most analogies fail to simulate the cumulative effects that are based on random disintegrations of great numbers of individual molecules. Several items are given below as examples of analogies which may be used for class demonstrations or laboratory exercises.

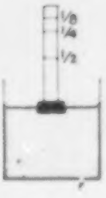
a. The rate of discharge of a capacitor through a resistor depends directly on the charge on the capacitor. Thus the decay of the charge will follow the same pattern as the decay of a radioactive element. If a vacuum-tube voltmeter is available, it may be used to measure the potential of a charged capacitor and simultaneously discharge it through the meter's resistance. A 1-μf. capacitor discharging through the usual vacuum tube voltmeter will exhibit a "half-life" of about 7 seconds. If the capacitor is originally charged to, say 200 volts, and readings are taken of the time required for the potential to drop to 100, 50, and 25 volts, the data may be plotted to show the typical half-life curve.

b. If the school equipment does not include a vacuum-tube voltmeter, the rate of discharge may be measured, using a milliammeter. The resistor is chosen to give full-scale meter deflection with the d.c. source used. The capacitor is at least 8 μf. and preferably larger. The switch is closed, establishing a full-scale current in the meter and charging the capacitor. The discharge starts the instant the switch is opened. Readings are taken and results interpreted as in *a*.



c. The cooling curve of a warm substance shows a similar decline, in its asymptotic approach to room temperature, although the relationship involved is not of exactly the same type.

d. If water is siphoned from a tall hydrometer jar, the drop in water level resembles the decay of a radioactive substance. This is suitable for qualitative demonstration only, as a graph of the height of remaining liquid against time shows a very significant departure from the half-life curve. A closer similarity can be achieved by using a capillary siphon or a liquid much more viscous than water.



e. Water is permitted to discharge from a large can through a small hole punched in its bottom. A wooden float has a vertical cardboard scale attached. The scale is marked so that, when seen over the edge of the can, it indicates when the can is half full, one-quarter full etc. Like part *d*, this is useful only for qualitative purposes.

f. A large number of coins is mixed and spilled into a large flat tray. Those which fall heads-up are discarded and the procedure is repeated until all of the coins are gone. A graph of Log *N* vs time may be plotted with *N* being the number of coins remaining and each trial being considered a unit of time. If the number of coins is large the graph will be a straight line and the half-life of the coins can be determined. This should be repeated for several trials.

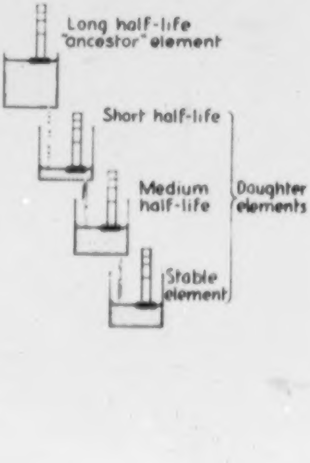
g. A large number of dice from a container are rolled and those coming to rest with a selected number uppermost are discarded. This analogy will have a longer half-life than the coins in paragraph *f* and therefore give better data for plotting the graph.

h. A quantity of small washers is placed in a cigar box which has a thin diagonal line ruled across the bottom. The box is closed and shaken. Then the box is placed on a level surface and the cover is opened. Any washers which touch the line are removed and the procedure is repeated until all of the washers have been removed. The larger the box and the greater number of washers used, the better the half-life graph. If this is used as a demonstration, a transparent box may be substituted and the experiment performed on an overhead projector.

i. A quantity of small styrofoam balls may be placed in a cylinder which can be rotated at a uniform speed with an electric motor. Baffles should be inserted in the cylinder to mix the balls in random patterns. The cylinder is closed and one or two holes are drilled in the surface each large enough to permit the passage of one ball. The balls are counted as they are ejected and a graph is constructed relating the log of the number remaining vs time. The half-life of the balls can be increased or decreased by changing the speed of cylinder rotation.

4.33. RADIOACTIVE SERIES

A radioactive disintegration always produces a different element. This daughter element may also be radioactive. A radioactive series can be illustrated by the flow of water from a can representing the "mother" element (U^{238}, for instance) into a series of other vessels.

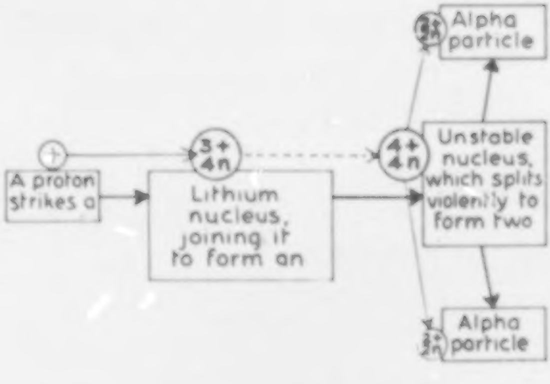


The long half-life ancestor is represented by a can with a very small discharge hole. The water is received in a can which has a larger hole in its bottom—resulting in a shorter "half-life." The series terminates in a stable element, a container which gradually fills. The water levels may be shown by vertical cardboard scales mounted on wooden floats. When a condition of equilibrium is reached (after replenishing the top can), the concentration of matter in long-half-life elements is apparent. The disappearance of the very short-half-life transuranic elements and the termination of the periodic chart of natural elements at long-half-life uranium can be discussed. An interesting sidelight on radioactivity is also easily described in terms of this demonstration. That is the possibility of estimating the age of the earth from measurements of the amount of lead in uranium-bearing rock.

4.34. EXPERIMENTAL PROOF THAT E = MC²

Scientists were convinced that Einstein had correctly stated the equivalence of mass and energy after they had made computations based on a number of artificial disintegration experiments. One of the most significant of these experiments can be used to illustrate this type of calculation. In 1932,Cockroft and Walton bombarded a thin film of lithium with protons, finding very energetic alpha particles as a product. This reaction can be represented diagrammatically. The nuclear equation is:

$$^{1}_{1}H + ^{7}_{3}Li \rightarrow (\text{unstable}) \rightarrow ^{4}_{2}He + ^{4}_{2}He$$


Alpha particle
+
3+
4n
4+
4n
A proton strikes a
Lithium nucleus, joining it to form an
Unstable nucleus, which splits violently to form two
Alpha particle

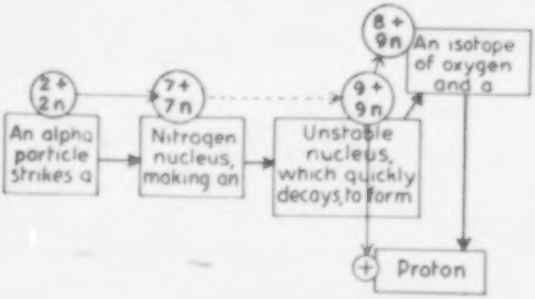
The alpha particles recoiled in almost opposite directions because they were driven apart with great energy as the result of the reaction. According to theory, one should be able to account for this energy by a disappearance of mass. Knowing the masses of the original substances and of the products by mass spectrograph result, it was possible to tell just how much mass had disappeared, and when this was converted to energy by Einstein's formula and the energy of the original proton was added, it turned out to be within 1 percent of the measured energies of the alpha particles. This computation is given in detail in college texts.

4.35. THE FIRST ARTIFICAL TRANSMUTATION

Students can be given practice in explaining nuclear events and in using the associated terminology by studying actual cases. Rutherford's experiment, in which protons and oxygen were produced by bombarding nitrogen with alpha particles, is one of the most famous. The alpha particles were emitted by radium in a tube containing nitrogen gas. Much to the scientists' amazement high energy protons were produced. After eliminating several other possible explanations, the following was accepted:

$$^{4}_{2}\mathrm{He} + {}^{14}_{7}\mathrm{N} \rightarrow (\text{unstable}) \rightarrow {}^{17}_{8}\mathrm{O} + {}^{1}_{1}\mathrm{H}$$

In addition to illustrating a transmutation, this reaction can be used to show that the total number of protons after the reaction is the same as before, and the same is true of neutrons, so that such an equation must be "balanced." Use a chalkboard diagram similar to the one shown below to make this symbolic equation meaningful.

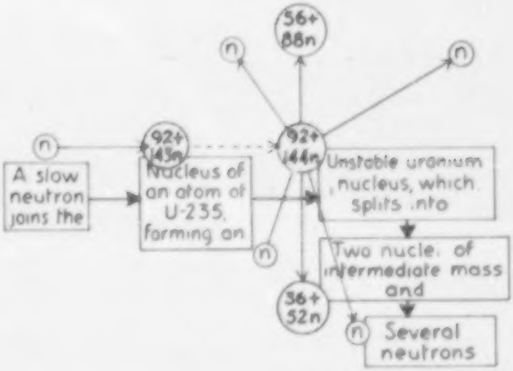

2 +
2 n
An alpha particle strikes a
7 +
7 n
Nitrogen nucleus, making an
9 +
9 n
Unstable nucleus, which quickly decays to form
8 +
9 n
An isotope of oxygen and a
+
Proton

4.36. FISSION OF URANIUM

A chalkboard diagram can be used to illustrate the fission of uranium.

The following points may be made:

- The product nuclei fly apart in opposite directions with enormous velocities.
- The liberation of energy results from the fact that the products have less mass than the original uranium nucleus and neutron combined. Nuclei near the center of the periodic table have less mass per particle than uranium has.
- A great variety of product nuclei may be formed.
- Since the proportion of neutrons goes up with atomic number, splitting uranium into two elements of lower atomic number results in product nuclei with too many neutrons for stability. The fission products are usually radioactive.
- Some of the excess neutrons are freed in the fission process, making a chain reaction possible.


n
A slow neutron joins the
92+
143n
Nucleus of an atom of U-235, forming an
92+
144n
Unstable uranium nucleus, which splits into
Two nuclei of intermediate mass and
Several neutrons
56+
88n
36+
52n
n
n
n
n

4.37. MODERATORS

The action of a moderator in a nuclear reactor is an application of the laws of conservation of energy and conservation of momentum. The impacts between the neutrons and the nuclei of the moderating material are elastic.

a. Show the loss of energy of a neutron when it strikes another atom by using the apparatus described in 1.38. When a steel ball strikes another of the same size, it is analogous to a neutron striking a hydrogen nucleus. Complete transfer of energy takes place if the impact is "head-on." Glancing impacts result in partial transfer of energy. For any angle of approach, the neutron will lose the greatest proportion of energy in striking a particle of nearly its own mass. Allow a small steel ball to strike a large one, to show that it rebounds with a large fraction of its original velocity. This illustrates the need for using substances low in the periodic table, such as hydrogen, deuterium and carbon, as moderators and reflectors of neutrons.

b. The same demonstration can be performed by sliding a disk such as a shuffleboard counter, a checker or even a coin across a smooth surface and causing it to hit a similar disk. To show the smaller decrease in velocity caused by an impact with a more massive nucleus, use a target made by stacking three or four disks and holding them together with cement or tape.

INDEX TO LEARNING ACTIVITIES

Absolute zero, Charles' law and (1.66)
Absorption of radiation (4.30)
Acceleration and force (1.24)
Acceleration of free fall, determining the (1.29)
Acceleration of gravity independent of mass (1.12)
Acceleration of gravity with a pendulum (1.11)
Acceleration, uniform (1.05)
Action and reaction apparatus, conservation of momentum using (1.34)
Air lens (2.52)
Air resistance, effect of, on falling objects (1.13)
Air thermometer, Galileo's (1.50)
Alpha particles, ionization of air by (4.27)
Alpha particles, scintillations caused by (4.26)
Alnico magnets (3.54)
Alternate methods of demonstrating wave motion (2.13)
Aluminum foil in a magnetic field, force on (3.49)
Amplifying the signal from a Geiger counter (4.18)
Analog, a scattering (4.11)
Analogy, Geiger tube (4.13)
Artificial transmutation, the first (4.35)
Attraction and repulsion (3.03)
Audible beats (2.30)

Background radiation (4.23)
Balmer series, the, and Planck's constant (4.12)
Beats, audible (2.30)
Beats using phased pendulums, the principle of (2.29)
Beta from gamma radiation, distinguishing, with a Geiger counter (4.31)
Beta particle scattering, relationship of, and the density of the scatterer (4.29)
Beta particles, reflection of (4.28)
Binding energy (4.21)
"Blinky" - relaxation oscillator light source (1.03a)
Boiling (1.55)
Boiling water, comparative heating effect of (1.60)
Bombardment, molecular (1.62)
Bright-line spectrum, the (2.66)
Brownian movement (1.62)

Calibration of a thermometer (1.52)
Cathode rays (3.64)
Cathode-ray tube, demonstrating the, with an oscilloscope (3.65)
Centrifuge, the (1.30)
Centripetal force and the plumb line (1.31)
Centripetal force measurement (1.32)
Charge, conservation of (3.06)
Charge, electric current and transfer of charge (3.14)
Charles' law and absolute zero (1.66)
Circuit, potential drop in a (3.12)
Circuit, series, the (3.22)
Circuits, heating in series and parallel (3.39)
Circuits, parallel (3.34)
Circular and straight pulses in a ripple tank (2.06)
Clock, stop, electric (1.08)
Cloud chamber, diffusion (4.15)
Cloud chamber, Wilson, the principle of the (4.14)
Coil of a television set, electromagnet from (3.46)
Collisions, photon-particle (4.09)
Colors, interference (2.56)
Comparative heating effect of steam and boiling water (1.60)
Comparison of rheostat and potentiometer (3.31)

Components, resolving a force into (1.20)
Conduction and induction, electrostatic (3.07)
Conduction in gases (3.16)
Conductivity of solutions (3.15)
Conservation of charge (3.06)
Conservation of energy, fluid friction and (1.44)
Conservation of energy - Galileo's experiment (1.42)
Conservation of momentum (1.33)
Conservation of momentum and kinetic energy (1.38)
Conservation of momentum, the laws of motion and (1.35)
Conservation of momentum using action and reaction apparatus (1.34)
Construction of geiger counters (4.17)
Continuous spectrum dispersion and the projection of a (2.46)
Convex lens - description of image (2.50)
Convex lens - size and distance of image (2.53)
Cooling by evaporation (1.59)
Cooling effect of ice and ice water (1.56)
Cooling through the freezing point (1.57)
Coulomb's law (3.08)
Counter, Geiger, amplifying the signal from a (4.18)
Counter, Geiger, distinguishing beta from gamma radiation with a (4.31)
Counter, Geiger, using a (4.18)
Counters, Geiger, construction of (4.17)
Current-carrying conductor in field, induction and motion of (3.56)
Current-carrying liquid in a magnetic field, force on (3.47)
Current, electric, and transfer of charge (3.14)
Current, heating effect of a (3.36)
Current, the magnetic effect of a (3.43)
Currents, eddy, and Lenz's law (3.59)
Currents, eddy, and magnetic brake (3.60)
Curtain rod analog, vector addition using a (1.17)
Curtain rod analog, vector resolution into right angle components using a (1.19)

D.C. generator, the (3.61)
Decay, exponential (4.32)
Deceleration, measuring, of a friction toy (1.09)
Demonstrating the cathode-ray tube with an oscilloscope (3.65)
Demonstration galvanometer (3.53)
Demonstrations, increasing the visibility of magnetism (3.40)
Demonstrations, setting up a "slinky" for (2.01)
Demonstrations, temperature indicators for (1.49)
Dependence of index of refraction on wavelength (2.47)
Description of image, convex lens (2.50)
Detection of radiation with film (4.16)
Diffraction (2.10)
Diffraction grating, wavelength of light using a spectral source and a (2.59)
Diffused and regular reflection (2.39)
Diffusion cloud chamber (4.15)
Diffusion of gases (1.65)
Diffusion, separation of isotopes by (4.22)
Diode, thermionic emission and the (3.63)
Discharge from points (3.09)
Discharges in gases (3.17)
Dispersion (2.49)
Dispersion and the projection of a continuous spectrum (2.46)
Dispersion of water waves (2.09)
Dispersion with a water prism (2.48)
Distances and displacements, measuring (1.02)
Distinguishing beta from gamma radiation with a Geiger counter (4.31)
Doppler effect, the (2.12)

Doppler effect, the, pitch shift (2.20)
Doppler effect, using a revolving buzzer (2.21)
Double reflection, polarization by (2.63)
Drop, line (3.30)
Drop, potential, in a circuit (3.12)

$E = MC^2$, experimental proof that (4.34)
Eddy currents and Lenz's law (3.59)
Eddy currents and magnetic brake (3.60)
Effect of a current, the magnetic (3.43)
Effect, the photoelectric (4.01)
Efficiency of an electric stove (3.38)
Electric current and transfer of charge (3.14)
Electric fields (3.10)
Electric fields, mapping (3.11)
Electric potential (3.13)
Electric power, measurement of (3.35)
Electric stop clock (1.08)
Electric stove, efficiency of (3.38)
Electrical equivalent of heat (3.29)
(Electricity) general suggestions (3.01)
Electromagnet from focus coil of a television set (3.46)
Electromagnet, strength of an (3.44)
Electrometer for measuring photocurrent (4.05)
Electrophorus, the (3.04)
Electroscopes (3.02)
Electrostatic conduction and induction (3.07)
Electrostatic machine, the (3.05)
Emission, thermionic, and the diode (3.63)
Emitter, photoelectric, work function and threshold frequency of a (4.08)
Energy and the hydraulic ram (1.41)
Energy and the piledriver (1.39)
Energy, binding (4.21)
Energy, fluid friction and conservation of (1.44)
Energy, heat as a form of (1.46)
Energy, heat equivalent of mechanical (1.47)
Energy, photon (4.06)
Energy, potential and kinetic (1.43)
Energy, transfer of, sensitive flame and (2.23)
Equilibrium of three concurrent forces (1.16)
Equivalent of heat, electrical (3.29)
Evaporation, cooling by (1.59)
Experimental proof that $E = MC^2$ (4.34)
Experiments, monochromatic light sources for (4.04)
Exponential decay (4.32)
Eye, inversion of image in the (2.51)

Falling objects, effect of air resistance on (1.13)
Field, earth's magnetic, generation using the (3.57)
Field, induction and motion of current-carrying conductor in (3.56)
Field, magnetic (3.42)
Field, magnetic, force on aluminum foil in a (3.49)
Field, magnetic, force on ionized gas in a (3.51)
Field, magnetic, of a solenoid (3.45)
Field, the vector nature of a magnetic (3.41)
Fields, electric (3.10)
Fields, electric, mapping (3.11)
Film, detection of radiation with (4.16)
Fission of uranium (4.36)
Flame, ions in (3.18)
Fluid, friction and conservation of energy (1.44)
Flux density of a magnet (3.50)
Focus coil of a television set, electromagnet from (3.46)

Force, acceleration and (1.24)
Force and motion (1.23)
Force into components, resolving a (1.20)
Force measurement, centripetal (1.32)
Force on a stiff wire in a magnetic field (3.48)
Force on aluminum foil in a magnetic field (3.49)
Force on current-carrying liquid in a magnetic field (3.47)
Force on ionized gas in a magnetic field (3.51)
Forces, acting on car on incline (1.18)
Forces, composition of (1.15)
Forces, equilibrium of three concurrent (1.16)
Forces, the concepts of (1.14)
Free fall, determining the acceleration of (1.29)
Freezing point, cooling through the (1.57)
Frequency, wavelength, velocity (2.07)
Friction (1.45)
Friction and conservation of energy, fluid (1.44)
Fuses (3.37)

"g," dependence of pendulum period on (1.10)
Galileo's air thermometer (1.65)
Galileo's experiment, conservation of energy (1.42)
Galvanometer, demonstration (3.53)
Gamma radiation, distinguishing beta from, with a Geiger counter (4.31)
Gas-filled tube, photocurrent in a (4.02)
Gas volume with pressure, variations of (1.67)
Gases, conduction in (3.16)
Gases, diffusion of (1.65)
Gases, discharges in (3.17)
Gases, refraction by (2.41)
Geiger counter, amplifying the signal from a (4.18)
Geiger counter, distinguishing beta from gamma with a (4.31)
Geiger counter, using a (4.19)
Geiger counters, construction of (4.17)
Geiger tube analogy (4.13)
Generation using the earth's magnetic field (3.57)
Generator, the D.C. (3.61)
Generators and Lenz's law (3.62)
Gravitational mass, inertial and (1.26)
Gravity, acceleration of, independent of mass (1.12)
Gravity with a pendulum, acceleration of (1.11)

Heat as a form of energy (1.46)
Heat, electrical equivalent of (3.29)
Heat equivalent of mechanical energy (1.47)
Heat, measurement of specific (1.54)
Heat of fusion of water (1.58)
Heat of vaporization (1.61)
Heat, the distinction between temperature and (1.48)
Heating effect of a current (3.36)
Heating effect of steam and boiling water (1.60)
Heating in series and parallel circuits (3.39)
Heats, comparison of specific (1.54)
Hydraulic ram, energy and the (1.41)

Ice and ice water, comparative cooling effect of (1.56)
Image, convex lens - description of (2.50)
Image, convex lens - size and distance of image (2.53)
Image in a plane mirror, characteristics of (2.34)
Image in the eye, inversion of (2.51)
Image, virtual nature of plane mirror (2.35)
Images, "reversal" of mirror (2.36)
Index of refraction, measurement of (2.42)

Index of refraction of a liquid (2.43)
Index of refraction on wavelength, dependence of (2.47)
Indicators for demonstrations, temperature (1.49)
Inertia, demonstrations of (1.21)
Induced voltages (3.55)
Induction and motion of current-carrying conductor in field (3.56)
Induction, electrostatic conduction and (3.07)
Inertial and gravitational mass (1.26)
Intensity, variation of radiation, with distance (4.25)
Interference analogy with pocket combs (2.25)
Interference analogy with projected moire patterns (2.26)
Interference colors (2.56)
Interference in sound of tuning forks (2.27)
Interference of light (2.55)
Interference of sound waves (2.28)
Interference pattern produced by two point sources (2.11)
Interference produced by two slits (2.57)
Interference, single-slit (2.60)
Internal reflection, total (2.45)
Internal resistance (3.33)
Inversion of image in the eye (2.51)
Ionization of air by alpha particles (4.27)
Ionized gas in a magnetic field, force on (3.51)
Ions in flame (3.18)
Isotopes, separation of, by diffusion (4.22)

Jet reaction, water (1.36)

Kinetic energy, and potential (1.43)
Kinetic energy, conservation of momentum and (1.38)
Kinetic molecular theory (1.62)

Lamp as a tester, use of the neon (3.20)
Laser beams and optics demonstrations (2.68)
Law, Coulomb's (3.08)
Law, generators and Lenz's (3.62)
Law, Lenz's (3.58)
Law, Lenz's, eddy currents and (3.59)
Law, Newton's, second (1.22)
Law of motion, second, puzzle (1.25)
Law of reflection, the (2.33)
Law, Ohm's (3.19)
Laws of motion, the, and conservation of momentum (1.35)
Law of resistance (3.21)
Laws of resistance (quantitative (3.22)
Lens, air (2.52)
Lens - convex, description of image (2.50)
Lens - convex, size and distance of image (2.53)
Length of radio waves (2.19)
Lenz's law (3.58)
Lenz's law, eddy currents and (3.59)
Lenz's law, generators and (3.61)
Light, interference of (2.55)
Light, polarization of (2.61)
Light source, monochromatic (2.32)
Light sources, monochromatic, for photoelectric experiments (4.04)
Light, using a slide projector to measure the wavelength of (2.58)
Light using a spectral source and a diffraction grating, wavelength of (2.59)
Line drop (3.30)

Machine, the electrostatic (3.05)
Magnet, flux density of a (3.50)
Magnetic brake, eddy currents and (3.60)
Magnetic effect of a current, the (3.43)
Magnetic field (3.42)
Magnetic field, force on aluminum foil in a (3.49)
Magnetic field, force on a stiff wire in a (3.48)
Magnetic field, force on current-carrying liquid in a (3.47)
Magnetic field, force on ionized gas in a (3.51)

Magnetic field, generation using the earth's (3.57)
Magnetic field of a solenoid (3.45)
Magnetic field, the vector nature of a (3.41)
Magnetism demonstrations, increasing the visibility of (3.40)
Magnets, alnico (3.54)
Magnets, permanent (3.52)
Mapping electric fields (3.11)
Mass, inertial and gravitational (1.26)
Mass of a "weightless" object (1.27)
Mass spectrograph, a model (4.20)
Measurement of electric power (3.35)
Measurement of index of refraction (2.42)
Measurement, power (1.40)
Measurements, statistical, nuclear physics, nature of (4.24)
Measures, metric mass and weight (1.28)
Measuring deceleration of a friction toy (1.09)
Measuring distances and displacements (1.02)
Measuring photocurrent, electrometer for (4.05)
Mechanical energy, heat equivalent of (1.47)
Medium, speed of sound depends on (2.17)
Medium, transmission of sound through a (2.24)
Metric mass and weight measures (1.28)
Mirror image, virtual nature of plane (2.35)
Mirror images "reversal" of (2.36)
Mirror, plane, characteristics of an image (2.34)
Mirror tricks and special applications (2.38)
Model mass spectrograph, a (4.20)
Models, nuclear (4.10)
Moderators (4.37)
Moire patterns, interference analogy (2.26)
Molecular bombardment (1.63)
Momentum and kinetic energy, conservation of (1.38)
Momentum, conservation of (1.33)
Monochromatic light source (2.32)
Monochromatic light sources for photoelectric experiments (4.04)
Motion, analyzing by stroboscope photography (1.07)
Motion and conservation of momentum, the laws of (1.35)
Motion, and force
Multiple reflections (2.37)

Neon lamp as a tester, use of the (3.20)
Newton's rings (2.54)
Newton's second law (1.22)
Nuclear models (4.10)
Nuclear physics measurements, statistical nature of (4.24)

Ohmeter (3.24)
Ohm's law (3.19)
Ohm's law and temperature variations (3.28)
Ohm's law and the rheostat (3.25)
Optics demonstrations, laser beams and (2.68)
Origin of waves in vibrating matter (2.22)
Oscilloscope, demonstrating the cathode-ray tube with an (3.65)

Parallel circuits (3.34)
Parallel circuits, heating in series and (3.39)
Pendulum, acceleration of gravity with a (1.11)
Pendulum period, dependence on "g" (1.10)
Pendulums, the principle of beats (2.29)
Periodic waves and pulses on a "slinky" (2.02)
Permanent magnets (3.52)
Phased pendulums, the principle of beats (2.29)
Photocurrent, electrometer for measuring (4.05)

Photocurrent in a gas-filled tube (4.02)
Photoelectric effect, Planck's constant and the (4.07)
Photoelectric effect, the (4.01)
Photoelectric emitter, work function and threshold frequency of a (4.08)
Photoelectric experiments, monochromatic light sources for (4.04)
Photon energy (4.06)
Photon-particle collisions (4.09)
Piledriver, energy and the (1.39)
Pitch shift, the Doppler effect (2.20)
Planck's constant (4.03)
Planck's constant and the photoelectric effect (4.07)
Planck's constant, the Balmer series and (4.12)
Plane mirror, characteristics of an image in (2.34)
Plane mirror image, virtual nature of (2.35)
Plumb line, centripetal force and the (1.31)
Points, discharge from (3.09)
Polarization by double reflection (2.63)
Polarization by reflection (2.62)
Polarization by scattering (2.64)
Polarization of light (2.61)
Potential and kinetic energy (1.43)
Potential drop in a circuit (3.12)
Potential, electric (3.13)
Potentiometer, comparison of rheostat and (3.31)
Power measurement (1.40)
Power, measurement of electric (3.35)
Pressure, variations of gas volume with (1.67)
Prism, dispersion with a water (2.48)
Proof that $E = MC^2$, experimental (4.34)
Pulses and periodic waves on a "slinky" (2.02)
Pulses in a ripple tank, circular and straight (2.06)
Puzzle, second law of motion (1.25)

Radiation, absorption of (4.30)
Radiation, background (4.23)
Radiation, detection of, with film (4.16)
Radiation intensity, variation of, with distance (4.25)
Radioactive series (4.33)
Radio waves (2.67)
Radio waves, length of (2.19)
Rainbow (2.44)
Rays, cathode (3.64)
Reaction, water jet (1.36)
Reflection, diffused and regular (2.39)
Reflection, double, polarization by (2.63)
Reflection of beta particles (4.28)
Reflection, polarization by (2.62)
Reflection, the law of (2.33)
Reflection, total internal (2.45)
Reflections, multiple (2.37)
Refraction by gases (2.41)
Refraction, by glass plate (2.40)
Refraction, measurement of index of (2.42)
Refraction of a liquid, index of (2.43)
Refraction of water waves (2.08)
Refraction on wavelength, dependence of index of (2.47)
Relationship of beta particle scattering and the density of the scatterer (4.29)
Relaxation oscillator light source (1.03a)
Repulsion, attraction and (3.03)
Resistance by voltmeter-ammeter method (3.23)
Resistance, effect of temperature on (3.27)
Resistance, internal (3.33)
Resistance, laws of (3.21)
Resistance of the human skin and body (3.26)
Resistance on falling objects, effect of air (1.13)
Resistance (quantitative) the laws of (3.22)

Rheostat and potentiometer, comparison of (3.31)
Rheostat, Ohm's law and the (3.24)
Rings, Newton's (2.54)
Ripple tank, circular and straight pulses in a (2.06)
Ripple tank, constructing and setting up a (2.04)
Ripple tank wave generator (2.05)
Ripple tanks, suggestions on the use (2.03)

Scalar quantities, and vector (1.01)
Scattering analog, a (4.11)
Scattering, polarization by (2.64)
Scattering, relationship of beta particle, and the density of the scatterer (4.29)
Scintillations caused by alpha particles (4.26)
Second law, Newton's (1.22)
Second law of motion puzzle (1.25)
Sensitive flame and transfer of energy (2.23)
Separation of isotopes by diffusion (4.22)
Series and parallel circuits, heating in (3.39)
Series circuit, the (3.32)
Series, radioactive (4.33)
Setting up a "slinky" for demonstrations (2.01)
Single-slit interference (2.60)
Slit, single- interference (2.60)
Slits, interference produced by two (2.57)
Solenoid, magnetic field of a (3.45)
Solutions, conductivity of (3.15)
Sound depends on medium, speed of (2.17)
Sound of tuning forks, interference in (2.27)
Sound through a medium, transmission of (2.24)
Sound waves, interference of (2.28)
Sources, ultraviolet (2.65)
Specific heats, comparison of (1.53)
Specific heats, measurements of (1.54)
Spectral source and a diffraction grating, wavelength of light using a (2.59)
Spectrograph, mass, a model (4.20)
Spectrum, dispersion and the projection of a continuous (2.46)
Spectrum, the bright line (2.66)
Speed of sound depends on medium (2.17)
Standing waves (2.31)
Statistical nature of nuclear physics measurements (4.24)
Strength of an electromagnet (3.44)
Stroboscopic photography, analyzing motion by (1.07)
Suggestions, general (electricity) (3.01)
Suggestions on the use of ripple tanks (2.03)

Tanks, ripple, suggestions on the use of (2.03)
Temperature and heat, the distinction between (1.48)
Temperature indicators for demonstrations (1.49)
Temperature on resistance, effect of (3.27)
Temperature variations, Ohm's law and (3.28)
Tension in tug-of-war rope (1.37)
Tester, use of the neon lamp as a (3.20)
Theory, kinetic molecular (1.62)
Thermionic emission and the diode (3.63)
Thermometer, calibration of a (1.52)
Thermometer, Galileo's air (1.50)
Thermometer, principle of the (1.51)
Threshold frequency of a photoelectric emitter, work function and (4.08)
Ticker tape timer, calibrating a (1.03)

Torsional wave demonstrators (2.16)
Total internal reflection (2.45)
Transfer of charge, electric current and (3.14)
Transfer of energy, sensitive flame and (2.23)
Transmission of sound through a medium (2.24)
Transmutation, the first artificial (4.35)
Transverse wave in a spring or rubber tube (2.15)

Ultraviolet sources (2.65)
Uniform acceleration (1.05)
Uniform acceleration with a rotating disk (1.06)
Uniform velocity (1.04)
Uranium, fission of (4.36)
Use of the neon lamp as a tester (3.20)
Using a slide projector to measure the wavelength of light (2.58)

Vaporization, heat of (1.61)
Variations of gas volume with pressure (1.67)
Vector addition using a curtain rod analog (1.17)
Vector and scalar quantities (1.01)
Vector nature of a magnetic field, the (3.41)
Vector resolution into right angle components using a curtain rod analog (1.19)
Velocity, frequency, wavelength (2.07)
Velocity, uniform (1.04)
Vibrating matter, origin of waves in (2.22)
Voltages, induced (3.55)
Voltmeter-ammeter method, resistance by (3.23)
Volume with pressure, variations of gas (1.67)

Water, heat of fusion of (1.58)
Water prism, dispersion with a (2.48)
Wave demonstrators, torsional (2.16)
Wave generator, ripple tank (2.05)
Wave in a spring or rubber tube, transverse (2.15)
Wavelength, dependence of index of refraction on (2.47)
Wavelength of light, using a slide projector to measure the (2.58)
Wavelength of light using a spectral source and a diffraction grating (2.59)
Wavelength, velocity, refraction of (2.08)
Wave motion, alternate methods of demonstrating (2.13)
Wave of students, longitudinal (2.14)
Waves in a "slinky" (2.01)
Waves, interference of sound (2.28)
Waves in vibrating matter, origin of (2.22)
Waves on a "slinky," periodic and pulses (2.02)
Waves, radio (2.67)
Waves, radio, length of (2.19)
Waves, standing (2.31)
Waves, water, refraction of (2.08)
"Weightless" object, mass of a (1.27)
Weight measures, metric mass and (1.28)
Wilson cloud chamber, the principle of the (4.14)
Work function and threshold frequency of a photoelectric emitter (4.08)

APPENDIX

Equipment and supplies

A multiplicity of apparatus and supplies will be required to carry out the activities of this handbook. While it is not anticipated that all the experiments and demonstrations of this program will be performed in any one classroom, the activities which are not used in class may well make the basis for individual work on the part of students who wish to go beyond the classroom course. Schools should plan on regular additions of apparatus. Many of the pieces listed here can be constructed by students or the teacher, and several of the handbook activities give plans for such work.

It is suggested that teachers review the physics syllabus and the physics handbook together as an aid to calendaring the sequence of their course and determining supplies and equipment necessary for laboratory and demonstration use. During this review teachers might wish to categorize handbook inclusions for use as teacher demonstrations or as student laboratory exercises on an individual or group basis. Such items could be tentatively identified with a "D" for demonstrations or an "L" for student exercises. The letter "L" might be followed with a dash and a number from 1 through 4 to indicate the number of participants using the laboratory materials. From this information the teacher can estimate the total number of thermometers, galvanometers lenses, resistors, capacitances, etc. required.

Many of the "wave phenomena" entries can be handled on a multiple group basis as an efficient way of utilizing ripple tank equipment. Students working on an individual basis can very often use some items of equipment in common. A single mercury lamp, for example, may be used by a number of students simultaneously. A diffraction grating projection can also be used on an individual or group basis.

Teachers are urged to maintain a running inventory of supplies and equipment. By doing this they can arrange for maintenance, repair, and replacement as the needs arise.

Much of the equipment used in the physics laboratory is in common usage by other areas of the science department. These common items include: air-thermometer bulbs, aquariums, asbestos squares, platform balances, battery jars, beakers, electric bells, Bunsen burners, clamps, magnetic compasses, evaporating dishes, Erlenmeyer flasks, Florence flasks, graduated cylinders, magnets, meter sticks, power supplies, psychrometers, pulleys, ringstands, glass tubing, thermometers, tuning forks, metric masses, etc.

Sufficient quantities of the materials listed on the next page are also essential.

Apparatus

ammeters, d.c., 0-5
ammeter, a.c., 0-5
audio amplifier
audio generator
barometer, mercury
calorimeters (nickel-plated brass)
Charles' Law tube
electrophorus
electroscope, leaf
Galvanometer, lecture table
galvanometers, student type
Geiger counter
Hall's car or skate car
induction (spark) coil
linear expansion apparatus, each with two different test rods
loudspeakers, 4-inch, permanent magnet
magnetic needle, large, with stand
milliammeters, d.c., 0-10
milliammeter, d.c., 0-1
oscilloscope, cathode-ray, 5-inch
ripple tanks
spectrum chart
spectrum tube, neon
spectrum tube, helium
supports for meter stick optical bench
thermometers, ungraduated
thermostat, bimetallic
ultraviolet source
voltmeters, d.c., 0-10
voltmeter, d.c., 0-100
voltmeters, a.c., 0-10

Supplies

1 gal.	alcohol, methyl
6 doz.	candles, 2-cm. diam., 12 cm. long
6 to 30	dry cells
5	fuses, 5 amp. and 15 amp.
5 lb.	iron filings
10	lamps, flashlight, 2.5 volt
2	lamps, flashlight, 3.8 volt
1	lamp, automobile, 6-8 v., 32 cp.
4	lamps, 120 v., 8, 15, 25, 40, and 60 watt
1	lamp, carbon filament, 120 v., 32 cp.
12	lamps, neon glow, 2 watt
2	lamps, straight filament, 120 v.
1	lamp, photoflood, 120 v.
1 lb.	lead shot
1 sq.ft. ea.	metal sheet, aluminum, copper, lead, zinc, iron
2 lb.	mercury metal
5 lb.	modeling clay
1 lb.	paraffin
1 sq.ft.	plastic, clear, 1/2-inch thick
3 lb.	stoppers, rubber, assorted
1 lb.	sulfuric acid, concentrated
1	T-connecting tube, 15 mm. o.d.
1 lb.	tubing, glass 14 mm. o.d.
5 lb.	tubing, glass, 6 mm. o.d.
50 ft.	tubing, rubber, medium wall, 5/16-inch i.d.
100 ft.	tubing, rubber, medium wall, 3/16-inch i.d.
5 ft.	tubing, rubber, extra-heavy, wall, 1/4-inch i.d.
5 ft.	tubing, rubber, medium wall, 3/8-inch i.d.
4 oz.	vacuum wax
4 oz. ea.	wire, chromel, No. 22, 28
4 oz. ea.	wire, copper insulated, No. 20, 22, 24, 28, 30
1 lb.	wire, copper insulated, No. 26
4 oz. ea.	wire, iron, No. 18, 22
1 oz.	wire, German silver insulated, No. 30
100 ft.	wire, flexible test lead
200 ft.	wire, push-back